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What the Traveling Public Wants in the Future

By William B. Stout

President, Stout Engineering Laboratories, Inc.

"DON'T let any industry kid itself that it is not in the midst of an absolute change, and particularly if it be a transportation industry.

"This will not be a mere slight improvement or an addition of attachments and gadgets, but an absolute fundamental metamorphosis.

"Industry, after its bristling period in the market, went into a coma and disappeared entirely into the chrysalis of the experimental laboratory where it has been for four years. Now, under the impetus of the new day, it is emerging from this cocoon of experimentation no longer a narrow, short-sighted, crawling creature, but a butterfly with wings, preening itself in the sun and ready to take off almost any time for far more distant flights of progress than ever before in the history of mankind."

Mr. Stout thus summarizes his paper after having outlined the history of transportation with special references to the development of railroad building and operation and the competition with which the railroads were confronted after motor-vehicle and highway development had proceeded sufficiently far.

Among future trends and needs, Mr. Stout is impressed by present developments in the touring-trailer field, and suggests that in the very near future the public will respond to a vehicle complete in itself and somewhere half-way between the present touring car and the most luxurious trailer.

Light weight must be a fundamental of the future car, and great improvement in vision is an urgent necessity at present.

A GREAT change is going on in the world's transportation as well as in its humanity. New items of engineering are developing almost hourly, most of which are applicable to some phase of transportation—and transportation constitutes about 85 per cent of all human labor.

The first great transportation was by water. The moving of goods overland was too expensive. For the same reason the first inland developments in these United States started with river navigation; with canoes and boats that could be pushed or rowed or paddled. Over certain routes where the rivers were not navigable the canal was developed, representing the most stupendous engineering achievement of its day, around which the romance and social life of the period was developed. This enabled business to be carried on over certain aqueous arteries of trade. Then came steam and the locomotive; and certain cut-and-try engineers and blacksmiths worked together to evolve the steam engine and the railway. With the stupendous speed of 30 m.p.h., the time from New York to Albany cut by many days and the increased comfort of a bench in a car clattering over the rails, as compared with the bouncing of a post-chaise on the rutty road to Boston, passengers began to prefer rail travel and the world was entranced with the achievements of the men of the early day of the railroad as they crossed mountains and rivers, built bridges and tunnels and carried civilization westward on the romantic crest of the railroads' progress. Thus industry was developed along lines of travel inland from rivers and harbors.

Even in inland cities, factories began to spring up to serve the rails—the steel industry and the rolling of rails, foundries and flour mills, serving territories instead of locality—and the arm of commerce began in stretch out to longer distances from the base of supply to bring back wealth to the parent city. In all this the thing that prospered from the railroads was not so much the holder of railway stock or the

This paper is to be read at the International Automotive Engineering Congress, Chicago, August 30, 1933.

"In the coming of the motor-car industry, the world got its greatest awakening since Adam lost his rib."

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"Most thinking in this world is, perhaps, 'wish-thinking.'"

* * * * *

"It is not the truck or the bus that is the competition of the railroad; the chief item is the unit transportation of the privately owned automobile. When you and I want to go anywhere we climb into the car, step on the gas and are gone."

manager or superintendent of any particular road but the community which those rails served to enable them to do a type of business which was impossible in that locality previously, and after all, that is the mission of transportation. New cities sprang up and new industries came which were never dreamed of before—advertising, the traveling salesman, publications, magazines, illustrating—until the three basic industries of housing, food and clothing were more than balanced by the number of people occupied in other lines of work.

The railroad brought another thing in—a new habit of mind. People had used horses for thousands of years until the method of travel, road building and planning of cities, had become standardized, stabilized and stagnant. With the coming of the railroad improvements became the order of the day—powerplants of greater power, heavier rails, straighter lines of travel, better bridges, air brakes, sleeping cars and the like, and in this improvement lay the romance of this new world's job.

But, after many years, the same thing which had hit the horse transportation field through its century of progress got hold of the railroads. It was a source of income and parasites began to attach here and there to bleed away profit. Politicians got in their way and obtained their votes through the exploiting of every railroad incident to their own purpose. Every committee passed regulations to take something away from the railroads; the government started its insidious control regulating a thing it knew nothing of except as a political background; the unions laid down their rules to increase cost and cut efficiency and by so doing bound the railroad worker to a type of environment of overalls, grease and cinders, from which he has not been able to extricate himself even to this day. The post office department put in rulings regarding the design of cars; the rate commission dictating this and that until, finally, the inspiration and romance failed. Management felt, "What's the use" and in spite of management's knowing how a railroad should be run, things had to be done the way it said in a book which became yearly more antiquated. The railroads stagnated; false engineering stayed put; the idea that weight meant strength or safety still obtained; locomotives were written off on maintenance with no reference to obsolescence, even being put on the books at a 50-year life. The authors of such a command must have thought the world would stand still at their bidding.

When times were hard money had to be saved. The unions ruled that so many men per train had to be carried. Trains were eliminated; fewer trains with bigger locomotives and more cars were run with the public getting fewer schedules; goods were carted to the shipping platform, put on the train, carried to a destination, rehandled again, and after a while, with no promises, arrived at their destination in partially good condition. No competition in rails and service; therefore, no service—and no progress. The politician therefore left the poor old railroad standing rusting on its own rails, while he now forgot to declaim about this terrible "colossus" which was "crushing the poor laboring man" in the form of a railroad, because its value to him as a medium of ballyhoo oratory had passed, and he had found new things which he could bleed for profit and votes in new advances in civilization which some other man had developed and which he had now turned to prey upon and bring to equal ruin. For now had come transportation by road, the development of the gasoline engine and the perfection of the motor car. This is politics' new source of profit.

In the coming of the motor-car industry, however, the world got its greatest awakening since Adam lost his rib. We look upon our era of today when we may hop in a motor car and go anywhere any time, and scarcely stop to realize what this world was to our own fathers and how little different it was when they lived than when Caesar ruled, or when Moses took his tablets and went to the mountain.

In our own lifetime this world has changed more than in all history previously, and much of this change is due to the transportation furnished by the motor car and its direct effect on the psychology of the individual. With this coming the old divides of transportation vanished and a network of communicating roads took their place. The old idea of one long train a day was out, and one might leave in his motor car and start back home at any particular moment which his whim dictated. No longer must goods be rehandled during shipment, but must leave my door and be delivered to your door *muy pronto* and with no rehandling. If I wire you today, I want those goods in my storeroom tomorrow morning—not down town in a shipping room somewhere, lost in a consignment of eggs from Oshkosh—and if those eggs are to come to me I don't want any of them broken or hatched.

Science Links Industries

This change in psychology among Americans is perhaps the greatest gift of the motor car, and with it has come a mania for service on the part of manufacturers, executives, and those in industries quite apart from the fundamental of the politician, or any of those industries left over from the old horse or railroad days. This new ethics and this new service have developed a thousand and one new things for man to do for profit—tires, trucks, engines, steel, rubber goods, heat treating, metallurgy, lighting, heating, cooling, air conditioning, sound proofing, weather proofing, radio, medical, machinery, engineering and the like. Today there is hardly an industry that is not tied in with other industries through the network of scientific knowledge; which applies as well to the raising of cattle or the preparation of hides for leather, the performing of a major operation in a hospital or the X-ray examination of a metallurgical specimen, and yet the old industries still cannot see the new spirit that has come into the world.

Most thinking in this world is, perhaps, "wish-thinking."

If we wish for a new kind of steel or cast iron we begin to look around for ways of doing it, and so from an inspiration create a new thing. If we are running a railroad, however, and see a rattling motor vehicle hauling freight going down the road at 10 m.p.h. we have another kind of wish-thinking that dominates; for right away we say that crazy, slow, noisy contraption can never harm our railroad and so we pay no attention to it. The railroads laughed at the 20-m.p.h. truck trying to make deliveries over deeply rutted muddy roads, knowing that it could never compete with rail transportation; then, suddenly, good roads appeared and truck-trains passed and re-passed at 60 m.p.h., these trucks delivering from door to door with no rehandling. That developed new types of service to customers which the railroads had never thought of. The trucks could fit their schedules to any time of day or night and to the customers' desire; drivers were in uniforms and trained to courtesy; the noise got less and less; while the employes had better living conditions, higher wages, and a new romance for the public to center its attention upon.

Railroads Need Improved Service

The railroads, feeling the competition, rushed back to the politician in great disgust, appealing to him to pass laws to restrict the use of trucks, to cut size and decrease horsepower, to lessen their weight, and, in fact, to stop at every turn efforts which the new transportation made to improve business conditions in the line of transportation. Luckily, this effort was short lived, for those who had the real vision in the railroad business felt instead that this gave them a weapon to go back to those who had so standardized the railroad and explain how its then rusted out ideas and obsolescent methods had brought them to this impasse, and that it was time the railroad itself reorganized itself to give service which might compete with road transportation. But after all, it is not the truck or the bus that is the competition of the railroad; the chief item is the unit transportation of the privately owned automobile.

When you and I want to go anywhere we climb into the car, step on the gas and are gone. With our new vehicles we can make 80 m.p.h. at 20 miles per gal., if necessary, and in safety over straight, concrete highways with well-regulated traffic. We can take the family along on a 300-mile journey and make the trip for less money than we can go alone by railroad, all of which is an incentive to travel by road; and if there is a great deal of this transportation competing now with the railroads there will be four times as much when we really learn how to build automobiles for real safety and economy; and that is but a few years off. It is largely on account of the motor car that much of the railroad work must of necessity come to unit transportation with much more frequent schedules for passengers on the average run and even for freight, higher speeds and some type of door-to-door delivery on schedules which must better the motor truck in both cost and service. The railroad cannot side-step its problem by seeking restrictive laws. The canals tried that and their dominance is gone. We cannot stop progress.

Not long ago I talked with a prominent engineer regarding motor cars. "When we get this last gadget completed," he said, "that is the last thing I can think of which we can do to perfect the automobile." That reminds me of an advertisement which was exhibited at Chicago from a 1914 publication in which a manufacturer advertised "My Farewell Car." The advertisement went on to explain that he called this his farewell car because he believed that with all of the improvements which had been made in this model no major improvement would ever be made in the automobile. And you should have seen the photograph which accompanied the ad!

"There are greater possibilities now for new automobile companies to be organized and come into the business than ever before; and within a few years I predict many new names that have never been heard of in the automobile business, and new competition which will be running away with a considerable slice of the bacon now being consumed by those who consider themselves the permanently established manufacturing companies."

* * * *

"Complete elimination of both tramp and shimmy is hardly possible without the individual springing of every wheel without using definite cross-axles."

Perhaps one of the faults of the present-day automobile industry is that those closest concerned with it are having the greatest difficulty in seeing the necessity the public already sees as having to go into motor cars before being interested in the next step. That is why there are greater possibilities now for new automobile companies to be organized and come into the business than ever before; and within a few years I predict many new names that have never been heard of in the automobile business, and new competition which will be running away with a considerable slice of the bacon now being consumed by those who consider themselves the permanently established manufacturing companies.

Conquering this world is still a battle of ingenuity and always will be, and when all is said and done it is not the automobile engineer or the executive or the sales manager who runs the automobile business. The sales department cannot sell a vehicle the public does not want; the manufacturing department wastes its time building a vehicle that cannot be sold; the engineering department finds it impossible to design a motor car of any value by the use of the slide rule alone, for after all there is old John Q. Public and his wife and the friends he goes with that determine what is going to be purchased.

There is this great difference though that must not be forgotten. John Q. Public cannot design the new vehicle; he does not know what he wants until he sees it. When he sees it you may tell him it is streamlined or that it has an automatic this or that, or it may be just another automobile; but if his wife looks at it and says, "John, I want one," then the design is a success. The business of the automotive engineer therefore is to lead the purchasing public along the paths in which they should go; pointing the way to betterments, not just trick sales decoys, and to new things which are so obvious to the purchaser that you don't have to write a book for him to read before he knows what it is all about.

You can build a car as radical as you wish and as freak-

ish as you may desire; and if, when you set it on the road, it is fundamentally more beautiful than any previous automobile, you have made a tremendous start. You have sold the eye, and the eye is the very hardest thing to unsell once it is sold. "Beauty," it has been said, "is only skin deep," but that is enough for most men and most women. A good job of paint has sold many a motor car and many a flapper to her life's destiny; but of course the length of time before the divorce comes depends on the actual merit of the article, once possession is obtained. And while John Q. has been having some misgivings recently about the present-day car, he finds that conditions have changed; that he doesn't use his car for the things he used to use it for, that there are more varieties of motor vehicles necessary to suit his demands, and he is beginning to ask for new things. Just what is he going to want? What are these changing conditions? How are they to be met? One or two examples will suffice to show the tendency.

Throughout the West and South and for touring there has been one fairly recent development which perhaps has not had the recognition from the automobile business which its possibilities may deserve, and that is the touring trailer. Even admitting—and this may be all wrong—that the touring trailer field is very small and perhaps not a business at all, the fact that it has come into existence at all and has opened up its own market, even though limited, points out that there may be something there in a trend which the automobile man might at least study, if not definitely organize.

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The surprising thing about some of these trailers is what they do. Put them behind an ordinary roadster with a top and, instead of decreasing the speed of the car, top speeds will increase even though some 1500 lb. are added to the weight. The comfort of the passenger in the trailer is far beyond that obtained in the motor car itself, or, in fact, in any motor car. One can stand up and walk around in these comfortable vehicles. Sleeping accommodations are provided so that, in touring, the drivers may take turns so that day and night travel is possible. At noon hours instead of stopping and wasting 40 to 50 miles of progress, the table may be set up and thermos-and-canned-goods lunches served. One luxuriates in the interior of the trailer while the driver is the only one who feels the strain.

Providing for Touring Needs

The basic thing behind this trailer development comes from two sources; first, the summer tourist and camper who wants to go fishing and have a comfortable place to live in along beside a trout stream without the trouble of pitching camp and breaking up camp after a night's stop. This branch of the trade trailers fit very well, and this field probably will continue as a trailer project.

Another field, however, has been creeping up on us which is attracted to the trailer idea even though it does just not quite fit, and that is the long-distance tourists. In the old days, when we went out for a 1000-mile trip that was a tour. It took hours and hours over bumpy roads and the interior of our vehicles had to be like the old buggies where one could be bounced around all over the place, into the top and out of it without being seriously injured. Since trips were over short distances and of comparatively short duration, there was not much need for luxury and one recuperated in a hotel that night. Today, you and I have many friends who drive to Florida in the winter, a trip of several days; or to California, taking perhaps a full week for the journey.

For these people the trailer's luxuries and roominess are much to be desired, but the slower schedules in hilly country and difficulties on winding roads, and even some state restrictions as to size, hinder the trailer from ever becoming a primary touring vehicle. However, no firm today has designed a long-distance touring-car which combines head room, luxury, baggage space and equipment consistent with day and night touring over an extended period, and stayed in line with the requirements of a city vehicle for all ordinary uses. It is very probable that in the very near future old John Q. Public will respond to a vehicle complete in itself and somewhere half way between the present touring car and the most luxurious trailer. Certainly, on the same wheelbase, width and height of our present automobile, we can give to our public much more room, equipment, luxury and baggage space than we have ever attempted to give him before.

The grave mistakes in any line of engineering or industrial progress are practically always made in the assumption rather than in any detail of methods or building. The time has come when the assumptions on which the motor car business is based must be reshuffled to fit the new psychology of business, the new type of roads available, the new speeds required both for touring and city work, and the great reduction in fatigue for driver and passenger that is going to be necessary for all long-distance work. A drive of 500 miles in one day is not unusual now and, in a light car, it can be done without fatigue; but not in a heavy car, no matter what the advertising value of its name or the number of cylinders of its engines may imply.

Light weight must be a fundamental of the future car. Again we are getting to a type of roughness on the roads which is entirely different from the roughness on roads of the past such as in gravel ruts and on mud surfaces. Tramping of the front wheels on concrete, first one and then the other at certain synchronous speeds, is far worse than the rough-

ness of the old dirt roads. Shimmy of the front wheels at any time is more dangerous than the designer is willing to admit. Complete elimination of both of these is hardly possible without the individual springing of every wheel without using definite cross axles. The old cycle cars which some of us in the automobile business built "way back when" had cross springs instead of axles, and even with narrow treads we could out-ride and out-drive cars of much higher power and over much worse roads, simply because of the comfort to the occupants.

Quantity production is probably why manufacturers have not been forced to these new ideas before; but, now that we have come to a new deal, it is time that all these ideas be used at once in taking the next step and so the public is going to require individual wheel springs.

One of the great deficiencies of the old-type automobile—which is the type we are now driving and producing—is vision. We have fair vision forward when we are driving forward on a straight road but, when we come to a sharp cross-road, we are at a very definite disadvantage. We come into this street; say that it is full of traffic with cars parked clear up to the corner. We cannot see around the corner to find out whether anyone is coming from left or right until we have poked the nose or half of the car out into traffic. This must be done very slowly and carefully, else some unsuspecting driver on the main thoroughfare may knock the fenders and lamps off our car before we can even see whether he is coming. This long hood is not an item of safety in the present-day car. The corner posts are another bad item and the cause of many an accident. This is so obvious that it needs no further explanation, but only a solution. Worse than these though are the rear corner posts of the car.

There is almost no automobile in which the driver can look back before he makes a left or a right turn and be sure that no car is coming up on him before he makes the turn; he can only make a signal and hope that the car behind will see it, and at night this is a very poor hope. When he looks back, the rear corners of the car are directly in the way of his vision. Future cars should have clear vision all the way around—in back as well as in front—so that the driver can see everything that is approaching from every angle. With the thousands who are being killed each year in automobile accidents, the code of the automobile manufacturers should include the necessity for every possible safety measure that can be put into the design of their vehicle, and one of these first requirements is better vision.

Easy Operation Demanded

When we come to the controls of the car, there are many other items. John Public is all through buying cars which cannot be steered with one finger and without fatigue on high-speed trips. He wants his brake to work with just a touch of the foot without any possibility in any emergency of a squeak, a grabbing brake, or a chatter. Brakes must be smooth and velvety and perfectly equalized on both pairs of wheels, with just the proper pressure comparatively fore and aft to fit the particular balance of that individual make of car. Along with this ease of steering and comfort of operation comes the problem of the doughnut tire, the superballoon.

In spite of all talk that these big tires do not do this and do not do that, it is only a question of intelligence and study to make them do this and that which they cannot do now and still retain the easier luxury of low pressure which we all admit. The manufacturer may not want to put the big tire on but John Q. Public wants it and he is going to have it; so we might just as well cut our sales cost by giving him what he wants. The lighter the weight of the total car and its load, the easier is our problem of giving him this non-sway, easier rolling real air-cushion tire with a pressure of not over 8 lb. per sq. in. per wheel. This can still be done with easy steering even when standing still and without any of the difficulties which this type of tire gives on heavier cars; and by heavy cars I mean any car over 2500 lb. total weight when loaded.

"The time has come when the assumptions on which the motor-car business is based must be re-shuffled to fit the new psychology of business, the new type of roads available, the new speeds required both for touring and city work, and the great reduction in fatigue for driver and passenger that is going to be necessary for all long-distance work."

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"The code of the automobile manufacturers should include the necessity for every possible safety measure than can be put into the design of their vehicle, and one of the first requirements is better vision."

If there is any one fundamental of all future transportation that is going to be universal, it is that of light weight and the saving of every pound which can be taken off of every vehicle to add both to its performance and its luxurious riding. Again I want to reiterate what I have said to you now for many years, and which is just beginning to get recognition. It is that the lighter a car is, the easier it can be made to ride; the less the weight is, the greater is the comfort. And when we are getting down to cases on this light weight, we find that it can not only bring the better tires, the better steering, the less fatigue of control, and the lighter weight, but new types of powerplants, transmissions and what-not made possible only because of the greater power per pound available in the vehicle. Within five years we will see motor cars without gearshifts that will be able to climb our steepest highways on high gear without any effort at all.

And so the automobile is pointing a way in individual unit transportation toward a new deal when the individual on his own schedule of starting and returning will leave his home for any point within 400 to 600 miles for an easy day's journey; or he may plan to spend the night at it with several of the persons taking turns at driving and at sleeping in the commodious accommodations arranged within the car for the rest period. Roads will be better, allowable speeds will be higher, grades are already eliminated, traffic will be better regulated at the higher speeds, and safety much increased by better vision and greater controllability. Don't laugh when I say that the lighter weight and smaller engines as a result of your experience with aluminum heads will bring the air-cooled engine really into its own without competition just as it has done in aviation.

Analysis of Brake-Design Factors Gives Basis for Future Studies

By B. B. Bachman

Vice-President of Engineering, The Autocar Co.

THE importance of brakes on automobiles, trucks and buses always has been recognized. Traffic conditions and transport requirements which exist today have served to increase their importance. Relative to safety, this importance has been recognized by the laws which regulate automobiles. The regulations now existing are general in character where reference to construction is made, which frequently results in making their application difficult. Where results are specified, the question has arisen as to whether they conform adequately to present-day practice.

Naturally, the design of the brake mechanism and the factors which control the design need most careful consideration when the questions are being studied. Many of these factors are so elementary that they have not been included in the many papers and articles which have been written on the subject. Following, is an attempt to bring all these factors out in an elementary analysis.

Coefficient of Friction between Ground and Tire.—The force available for stopping a moving vehicle or holding a stationary vehicle on an incline is equal to the product of the weight of the vehicle and the coefficient of friction between the tire and the road surface, or $F = Wf$, where F is the retarding force; W, the weight of vehicle effective for braking; and f, the coefficient of friction between road and tire.

While the average value of this coefficient has undoubtedly tended to increase during recent years due to changes in road surfaces and tires, there is a wide variation due to water, oil, ice and the like, on the road. A value of 0.6 has been used for many years and, while under ideal conditions this may be considerably increased, it still is a fair value.

Effective Weight.—Relative to the foregoing, it is assumed that the total weight of the vehicle is effective, but it is obvious that this is rarely correct. The force F is the sum of the forces obtained from the product of the weight on each wheel equipped with brakes and the coefficient f. Taking a four-wheel vehicle with brakes on all wheels as an assumption, with the vehicle at rest on a level surface, the sum of the weight on the four wheels equals the total weight of the vehicle, or $W = 2W_F + 2W_R$, where W_F is the static load on one front wheel and W_R, the static load on one rear wheel.

If the vehicle is at rest on an inclined plane, then the total weight against the road surface is less than the total weight of the vehicle, but is still the sum of the weight on the individual wheels. For this condition $EW = W \cos \alpha$, where EW is the effective weight and α is the angle which the surface the vehicle rests upon makes with a horizontal plane. For grades encountered on modern roads, this factor does not have an effect greater than possibly 2 per cent and can be neglected. However, the distribution of the effective weight is changed by the angle of the incline, the relation of the height of the center of gravity above the road surface to the wheelbase, and the horizontal distance from a plane through the rear axle to a plane containing the center of gravity.

Referring to Fig. 1, if we call L the wheelbase; L_R, the horizontal distance from a plane through the rear axle to a plane containing the center of gravity; and h, the height of the center of gravity above the road surface; then $r = (h/L)$ and

$$2EW_F = EW\,[(L_R / L) + r \tan \alpha] \qquad (1)$$

In a passenger car, L_R/L is close to 0.5, and r probably is about 0.3; therefore, on a grade of 15 per cent the front-axle load is increased about 10 per cent. On trucks and buses the value of L_R/L is normally about 0.25; and of r, about 0.3 to 0.4. So, the front-axle load may be increased to the extent of 25 per cent. These figures apply, of course, to the front axle.

If the vehicle is being decelerated, there is also a change in the distribution of the effective weight on the wheels, dependent on the rate of deceleration and the relation of the height of the center of gravity above the road surface to the wheelbase and the distance from the center of gravity to the rear axle. Under this condition also, the total effective weight is equal to the sum of the wheel weights; but there is a question whether it is correct to assume that the total effective weight is available for braking, as will be discussed later.

[This paper was read Aug. 29, 1933, at the International Automotive Engineering Congress, Chicago.]

THIS paper is the result of activity started by an inquiry for assistance from a highway official which was referred to the National Automobile Chamber of Commerce and then to the Society.

A committee has been formed composed of Messrs. D. G. Roos, A. F. Coleman, F. K. Glynn, H. C. Dickinson and the author. As a first step, it was felt that an elementary analysis and outline of the general situation would be helpful, this to be followed by a series of conferences with representative men from the various interested organizations which would result in establishing data. Therefore, the paper is presented as the basis for discussion and criticism in the hope that it will lead to a helpful result.

The subjects which are elaborated include the coefficient of friction between ground and tire, effective weight, distribution of braking effort on front and rear wheels, maximum rate of braking, space available for brakes, brake types, factors influencing the arrangement of brakes, brake function, brake-control mechanism, pedal pressure, reaction time and brake rating. Mathematical analysis is applied wherever needed and interesting tabular data on trucks and buses are presented.

This transfer of weight is equal to the product of the retarding force and the height of the center of gravity above the road surface divided by the wheelbase. Then, under the action of the brakes,

$$2EW_F = EW\,[(L_R / L) + r\tan\alpha + fr] \qquad (2)$$

In a passenger vehicle, therefore, for the values assumed, the increase in front-wheel load may approach 45 per cent and, in a truck or bus, may run well over 100 per cent.

Distribution of Braking Effort on Front and Rear Wheels.—The braking effort on each wheel should be proportional to the weight on that wheel. We have seen under the heading "Effective Weight" that this weight varies over a considerable range. Therefore, if the braking effort on each wheel is proportioned to the static, level-road distribution, the full vehicle weight cannot be used to obtain the total braking effort as the front brakes will not have sufficient ability and the rear brakes will have an excess. On the other hand, if the braking effort on each wheel is distributed to bear a relation to the effective weight on the wheels under some assumed rate of deceleration, then it may be that under some condition of low traction the front wheels will be locked. It is possible that the brake effort on the front wheels can be somewhat in excess of the static distribution, but this will vary for different types of vehicles. To illustrate, the static distribution on a passenger car and a truck or bus is very dissimilar, as shown, and requires different treatment. Further, the difference between the loaded and the unloaded weight of these vehicles is also very different and must be considered.

It seems almost hopeless to arrive at the best arrangement by means of theory, particularly with any type of control used at present when the power applied to the brakes is distributed in a fixed ratio. Conceivably, there might be means introduced into the control mechanism which would change the distribution automatically in accordance with the requirements. In the absence of such a method, it seems safe to predict that the effective weight for braking is about 80 per cent of the total. This statement refers, of course, to emergency application only, which is but a minor part of all brake application. Therefore, we should write:

$$F = EW \times f \qquad (3)$$

Maximum Rate of Braking.—From the relation $F = Ma = (W/g)\,a$, where a is the rate of deceleration, we can derive $a = (Fg/W)$; and, as $F = EW \times f$, we have:

$$a = (EW \times f \times g) / W \qquad (4)$$

Therefore, if the effective weight of the vehicle could be taken at 100 per cent of W, the two items would cancel and we would have $a = f \times g$; and, for a value of 0.6 for f, the maximum deceleration would be 19.2 ft. per sec. per sec. However, when it is found necessary to reduce the effective weight as outlined, the value of a is reduced in proportion and the maximum deceleration is 15.35 ft. per sec. per sec.

As the distance in which a vehicle can be stopped from a given speed is

$$S = V^2/2a \qquad (5)$$

where S is the distance, in feet; V, the initial velocity in feet per second — 29.7 in this case; a, the rate of deceleration; and we have $S = 22.9$ ft. for the first case and 28.7 ft. for the second.

It may very properly be said that these figures have been beaten many times and no doubt they have been, due to a better condition of road surface than has been assumed, resulting in a higher value of f. However, the point it is desired to make here is not what can be obtained under ideal conditions, but what is safe to predict under reasonable conditions.

Space Available for Brakes.—The brakes must be attached either directly or otherwise to the wheels. If attached directly to the wheels, they are limited in diameter by the internal diameter of the tires less the space necessary for tire mounting. In width, they are limited to the space remaining between the wheel and/or the frame and spring in the rear, and on the front in the space remaining between the wheel and the tie-rod arm. If not attached directly to the wheels, they are limited to the driving wheels which are almost uni-

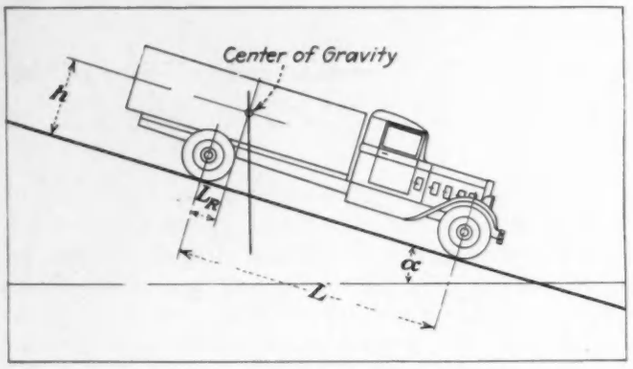


Fig. 1—Forces Acting on a Vehicle at Rest on an Inclined Plane

versally two only, unless special means are provided for attachment to the undriven wheels, which seems to be entirely unthinkable. Considering the conventional propeller-shaft brake as typical of a practical arrangement, the limit of diameter is the space between the body floor and a reasonable clearance line above the ground. The limitation in length is that over which the pressure can be evenly distributed on one shoe; or, if multiple shoes are used, the problem of equalization of effort between the shoe enters. Following, is an attempt to analyze these limitations in a quantitative manner, from Fig. 2.

On the front wheel, the sketch in Fig. 2 illustrates the conventional arrangement. To keep the stresses in the tie rod and tie-rod arm within reasonable limits, the distance *A* is made about 2½ in., maximum. This, in connection with a wheel-camber angle of about 1½ deg. and a king-pin angle of 6 to 8 deg., fixes the dimension *B* to a maximum of approximately 5 in. The tie rod being placed to the rear permits the converging of the arms and adds another 2 in. for *C*, or a total of 7 in. If a wood-spoke wheel is used, the space provided will accommodate a brake 3 in. wide; but, with a metal-spoke or disc wheel, which is practically universal, there is no trouble in increasing this. As to diameter, practice indicates that the effective brake diameter must be about 2¾ in. less than the tire-seat diameter, or 17¼ in. for a 20-in. tire, 19¼ in. for a 22-in. tire and 21¼ in. for a 24-in. tire.

On the rear brakes, the limitation of diameter is the same as on the front brakes. For width, the restrictions are illustrated in Fig. 3. By crowding the brake into the tire disc, a maximum of 8 in. can be obtained. This undoubtedly would lead to excessive temperature in the base of the tire and cause failure. A practical width would be 6½ in. This might be increased by moving the spring in under the frame, but Fig. 3 shows a spring-center distance of only 39¾ in., and this is certainly not too much to support a body which may be 96 in. wide and as many or more inches high. In fact, the springs which are shown as 3 in. wide would be much better if 4 in. wide, and this would reduce the brake width to 5½ in.

This analysis applies to the largest equipment and, as the size of vehicle is reduced, the limitations are less restrictive. However, the tendency to smaller tires on passenger cars produces a limitation in diameter which is more troublesome than the width limitation.

Brake Types.—There are several objections to the *external-drum brake;* (*a*) it is hard to make the shoe strong and rigid without using valuable space, (*b*) the drum cannot be provided with a reenforcing flange, (*c*) as the brake heats the drum, the drum expands and finally causes the brake to lock, and (*d*) it is difficult to provide shields against water and dirt.

The *internal-drum brake* has come into almost universal use as it can be most effectively installed in the space available, the drum can be effectively ribbed on the outside to add stiffness and radiation surface, and it also can be effectively shielded. Heating of the drum causes the drum to expand away from the shoe, thus avoiding self-locking but making necessary latitude in the operating mechanism to make possible the application of the brakes over a satisfactory period.

The *disc type of brake* is used only for indirect application, as it offers many difficulties to direct mounting on the wheels; also, the maximum diameter for an equal effective diameter is considerably greater than that of the internal-drum brake.

Factors Influencing Arrangement of Brakes.—When an analysis of the factors controlling the effectiveness of brakes is made as outlined and the requirements for vehicles operating under present-day conditions is considered, it will be evident that the service brakes will occupy all of the available space on the wheels. On account of limitations in diameter, the internal-drum brake is necessarily made in a width as limited by the other clearances discussed under "Space Available for Brakes."

If an independent secondary brake is required, it is obvious that this must be a driveshaft brake. For this reason, it can only be effective on the rear wheels; therefore, its effectiveness is determined by the effective weight on the rear wheels alone, as discussed under "Distribution of Braking Effort."

This secondary brake is generally called the "emergency brake," but this is an error. In the early days of the automobile and the truck, brakes were relatively ineffective and in many cases two sets of brakes were needed to stop or hold the car, due to their low efficiency. At that time, tire and wheel equipment was such that an internal and an external brake on the same drum could be mounted. This was never good construction due to the weakness of the drum and the interference with radiation of heat, but even if it were good it could not be done now on account of the closing-in of the tire.

As brake design and materials improved and the effectiveness of brakes improved and, finally, when brakes were mounted on the front wheels, it became evident that one set of brakes of proper size and with properly designed operating mechanism would supply all the braking that could be used due to other limiting factors. An emergency brake can, therefore, be required only if there should be a failure in the service brake.

Such a failure, if it occurs, is almost certain to be in the operating mechanism and not in the brakes themselves. If a failure occurs without the driver's knowledge until he needs to use the brake, the time lost in becoming aware of the failure and attempting to apply another brake is fatal if the need of the brake is imperative. If the failure occurs and the driver is aware of it so that a secondary system is needed to bring the vehicle to a place where repairs can be made, the driveshaft brake commonly used is less effective for the reason, first, that it is only operative on two wheels, and, second, on account of limitation in size and location, it has very much less thermal capacity. Therefore, in one emergency it is adequate because it cannot be brought into ac-

tion quickly enough, and in the other it is limited in capacity. From these facts, it is obvious that under present conditions the word "emergency" is a misnomer where applied to the auxiliary brake.

Brake Function.—The function of the brakes is to reduce the speed of a vehicle, stop it entirely, keep it from increasing speed on a hill or hold it stationary if standing on an incline. The first three of these functions can be performed most readily by a foot-operated brake, leaving the driver's hands free to steer, which is usually an equally important need, particularly in an emergency. When holding a vehicle under control on a long grade, there may be some advantage in a brake which can be set, but the general use of power-operated brakes on heavy vehicles has eliminated this need. To keep a car from rolling on a hill needs a means of application which can be mechanically held in the applied position. It is, of course, possible to provide such locking means on either a foot or a hand-control lever, but general usage has preferred the hand lever.

From this discussion and that under "Factors Influencing Arrangement of Brakes," it seems logical to state that the best performance and maximum safety can be secured by providing wheel brakes properly proportioned to the size of the vehicle and equipped with two independent means of control arranged in such a way that failure of any part of either control system will still leave operable brakes on at least two wheels. This principle has been recognized for some years and was the basis of the recommendations in the Hoover code, but some regulations still specify two completely independent brake systems. There would be ample justification for such a provision if it contributed in any degree to increase safety. This, however, is not the case and actually there is more than a suspicion that it has exactly the opposite effect. First, on most vehicles, except possibly the lightest, adequate wheel brakes should occupy all the space available. Therefore, to provide independent brakes means either a reduction in size of the service brakes to provide room for the secondary brake, or the mounting of the secondary brake on the driveshaft; and the first alternative is certainly not in the interest of efficiency or safety.

I have no intention of casting reflection on the driveshaft brake as a type, but the most perfunctory examination of many of them shows plainly that they can never be anything more than a standing brake. It is true that this is the use they are put to the greater part of the time; but, particularly on heavy vehicles, there are times when an auxiliary brake which is capable of bringing the vehicle to its operating base or some point where repairs or adjustments can be made is not only desirable, but necessary. The question of thermal capacity and the difficulty of providing for it in an adequate way on a driveshaft brake is, of course, the fundamental obstacle in making this type a satisfactory auxiliary to the service brake. Another point which is at least of some importance is the fact that, if one of the rear wheels is jacked up, the brake is gone until the wheel again makes contact with the road.

Brake-Control Mechanism.—From the discussion immediately preceding, it is evident that there should be two separate and independent means of brake control arranged so that failure of any part will still permit operation of the brakes or at least of two brakes on a four-brake job. Two systems are in general use for service-brake control; (*a*) mechanical and (*b*) fluid. Under (*a*) are included all conventional lever-and-rod constructions, together with cable controls. Under (*b*) are included both air and hydraulic systems.

In mechanical systems, the loss of a pin, the breaking of a rod or any similar mishap will not affect the whole system unless it happens to be the rod or pin connecting the pedal lever to the system or in the event of a fully equalized system which is very uncommon. In the fluid system, the failure of any part of the fluid system results in making the apparatus inoperative. In air-brake systems, it is possible to have the drop in pressure due to a leak cause an emergency application of the brakes. However, with any of these systems there is no great difficulty in arranging an auxiliary control-system which is completely independent of the service control down to the brake camshaft lever.

Pedal Pressure.—The effort which must be exerted by the operator in applying the brakes is, of course, a very important feature of proper control. In light vehicles there is no great difficulty in obtaining a pedal pressure satisfactory for a man, but with a large and increasing number of women drivers the need for extremely low pedal-pressures makes the problem more difficult. As the weight of the vehicle increases, the difficulty increases. Even though the operators of these heavier vehicles are generally more muscular, the large mileage they cover or the traffic conditions through which they operate makes a hard pedal a real disadvantage.

There is a very definite limit to the use of mechanical reduction in the control system to obtain low pedal-pressures. A pedal travel of 12 in. is the absolute maximum that can be considered, and this makes an arrangement of pedals far from comfortable. Not much over half of this amount can be considered really comfortable and between 3 and 4 in. makes by far the best arrangement. Any system, such as the mechanical or hydraulic, in which the pedal is in direct connection with the brakes, requires a relatively long pedal travel to provide the proper leverage and to eliminate the need of very frequent adjustment due to wear and expansion of the drums due to heating. Full power brakes, such as air brakes, are not subject to this limitation and, with

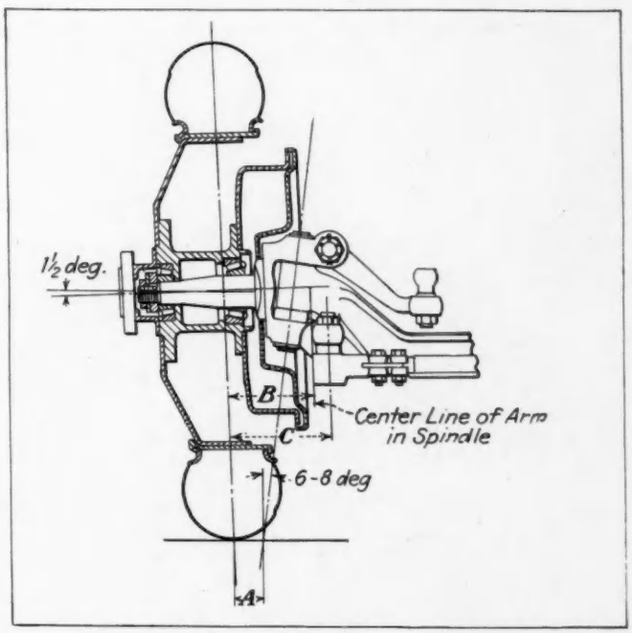


Fig. 2—Conventional Brake-Arrangement

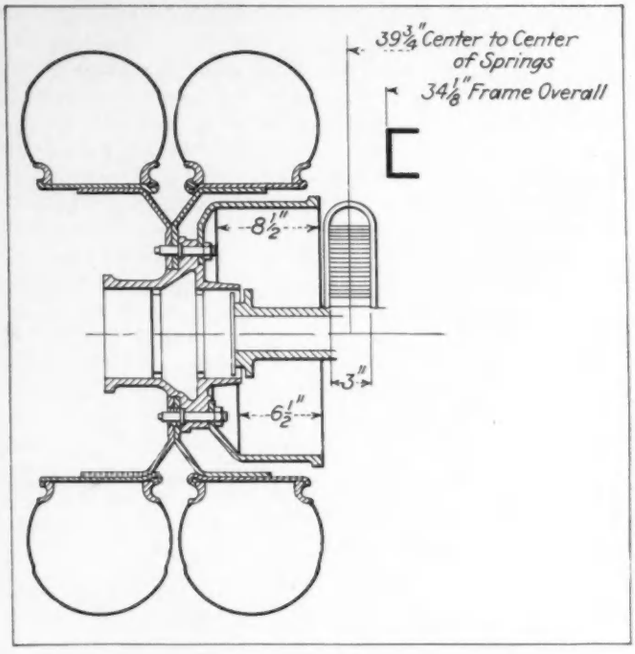


Fig. 3—Width Restrictions on Rear Brakes

them, both low pedal-pressure and short travel can be obtained easily.

Self-energizing types of brakes can and have been developed which help to reduce pedal pressure, but the number of variables which affect their operation makes their performance uncertain.

One very common fallacy regarding brakes is that increasing the width of a brake increases its effectiveness. This is true only if the power input to the brake is increased proportionately; or, in other words, the unit pressure between the drum and the shoe is maintained. Unless this is done, the only effect of making the brake wider is to decrease the unit pressure and thereby prolong the life, which is, of course, desirable and indirectly helps effectiveness by reducing the necessity for adjustment.

Reaction Time.—While it is obvious that a brake which requires a small effort can be applied more quickly than one which requires a relatively large effort, the time required for the operator to respond to a stimulus represents a definite factor in the question of how long it takes to stop a vehicle. This matter is outside of the scope of this discussion except insofar as location of the control is concerned. For the reason that the control elements, their position and means of operation, are generally similar and conventionalized in practice, this need not be elaborated further.

Brake Rating.—To evaluate easily the brake equipment of a given car, it would be desirable if the development of a rating method could be determined. The difficulty of doing this is appreciated, and I readily admit never having hitherto attempted to collect the criteria for brake design in an orderly manner. In this respect I am probably not greatly different from many others who, by diverse bumps, have gradually acquired a fund of experience to be drawn upon as occasion demands. What will be attempted in the following analysis is certainly not presented as a complete program, but rather as a target to excite comment, criticism and constructive thought.

A vehicle traveling at any given speed on a level road possesses kinetic energy which must be transformed in order to stop it. This energy $E = MV^2/2 = WV^2/2g$. The brakes will develop a torque T at the wheels, as expressed by

$$T = P \times MA \times e \times C \times K \times R_B \times G \qquad (6)$$

where

T = Brake torque in inch pounds
P = Pedal pressure; or, in power brakes, its equivalent in pounds
MA = Mechanical advantage between pedal or power source and the brake shoe
e = Efficiency of the control mechanism
C = Coefficient of friction between lining and drum
K = Coefficient of brake effectiveness
R_B = Effective radius of brake drum or disc in inches
G = Gear ratio between the brakes and the wheel

Equation (6) is a statement in a simple form which needs careful treatment for different types of control mechanism.

The force which can be developed at the periphery of the wheel to retard the vehicle is $BF = T/R_W$, where R_W is the rolling radius of the wheel in inches.

Under "Maximum Rate of Braking," the minimum practical distance in which a vehicle could be stopped was determined and this was called S. If we call the actual distance

Table 1—An Analysis of Six Trucks of Differing Sizes and Characteristics

Vehicle No.	Gross Vehicle Weight, Lb.	Value of (S / S_0)	Product of K, e and C	Brake Area, Sq. In.	Value of $(GxVxW)/A$	Maximum Speed, Ft. per Sec.	Speed Down Hill, Ft. per Sec.	BL_s Ft.-Lb. per Sq. In.	Ft.-Lb. per Sq. In. per Sec.	BL, Ft.-Lb.	Ft.-Lb. per Sq. In. per Sec.
1	16,000	2.04	0.490	450.0	35.5	85.8	29.7	4,050	725	22,370	125.0
2	22,000	2.35	0.425	519.0	42.4	59.5	29.7	2,330	602	23,745	133.5
3	24,000	2.09	0.477	519.0	46.3	59.5	29.7	2,540	655	25,905	144.5
4	28,000	2.10	0.475	663.5	42.2	51.0	29.7	1,705	513	23,432	131.5
5	28,000	2.57	0.389	599.0	46.2	64.3	29.7	3,010	720	27,957	133.5
6	30,000	2.52	0.397	663.5	46.0	48.5	29.7	1,650	522	25,008	140.0

in which the vehicle can be stopped from a consideration of the brake equipment S_a, then, for satisfactory brakes, $S/S_a = 1$. This means, of course, that the brakes can develop sufficient force at the ground to stop the car under the conditions of road and the like as defined. The value S_a can be obtained from the equation

$$S_a = \frac{E}{BF} = \frac{(WV^2/2g)}{(T/R_w)} = \frac{WV^2 R_w}{2gT} \qquad (7)$$

Therefore, after satisfactory values for the several variables are determined from practice, we might suggest for a rating for brake ability:

$$BA = \frac{S}{S_a} = \frac{(V^2/2a)}{(WV^2 R_w/2gT)} = \frac{gT}{aWR_w} \qquad (8)$$

Equation (8) would give a means of determining the ability of the brakes to stop the vehicle. As already pointed out, this is a function of the weight of the vehicle and the relation between the diameter of the brake and the wheel and the power applied to the brake. It gives no indication as to whether the brake is adequate in size to be satisfactory as to wear.

To determine the relative ability of brakes from the factor of life, a different analysis must be made. To stop the car from a given speed, the brakes must do an amount of work given by the value for E; therefore, we can define BL_s or brake life for a complete stop on a level road by:

$$BL_s = E/A = WV^2/2gA \qquad (9)$$

where A is the net area of the brake lining. From Expression (9) we see that the work which each unit of lining surface has to do varies directly as the weight and as the square of the velocity. However, it is probable that the work done by the brakes which affects the life most is in controlling the speed of a vehicle on a grade. In this case

$$E_T = \frac{W(V_1^2 - V_2^2)}{2g} + W \sin \alpha \times D \qquad (10)$$

where

V_1 = Initial speed when the brakes are applied
V_2 = Final speed down the grade
D = Distance over which the brakes are applied
α = Slope of the grade

Equation (10) is, of course, a more general expression and, if the conditions are a flat road, the second part disappears; and if the vehicle is brought to a complete stop the value for E is the result. Therefore, a complete statement for relative brake life would be:

$$BL = \frac{E_T}{A} = \frac{W(V_1^2 - V_2^2)}{2gA} + \frac{W \sin \alpha \times D}{A} \qquad (11)$$

If suitable values are established for V_1, V_2, α and D, for different types of vehicles, a reasonable factor can be established for this characteristic. It is possible that for light vehicles with high-speed capacity the first part of Expression (11) is most important and, for heavy vehicles with limited speed, the second part will predominate. Therefore, it might be well to obtain the values both for BL and BL_s and compare them to see which basis should be used to establish the design.

It will be noted that in this analysis the width of the brake becomes important and illustrates what has been referred to elsewhere; also, a comparison of wheel brakes and propeller-shaft brakes by this method will add a strong argument to the contention that the latter should only be considered of value as a standing brake. The problem of heat capacity and radiating ability seems too complex to treat satisfactorily, although the importance is obvious. However, it is very probable that a brake with good factors for BA, BL and BL_s, will be as good as it is possible to make it from a thermal basis. It is, of course, necessary to obtain data from present designs as to the factors and see how they compare with service records. An analysis of some vehicles is included in Table 1 as an illustration.

In Table 1, an analysis of six trucks of differing sizes and characteristics is made along the lines of the discussion. The calculations are based on a pedal pressure of 150 lb. and a booster pull of 680 lb. except for truck No. 5 which has air brakes and, in this case, a line pressure of 75 lb. per sq. in. was used.

In calculating brake torque, a value of unity was used for the coefficients K, e and C for the very good reason that I do not know what values should be assigned. It will be seen that this produces a value for S/S_a of from 2.04 to 2.52; therefore, by dividing these values into unity, the value of the product of K, e and C is obtained. In all probability, this is the way the matter will finally be developed if at all; that is, by a study of existing brake designs which produce

Table 2—Interesting Figures Applying to Trucks and Buses

Vehicle No.	Brake Area, Front, Sq. In.	Weight per Sq. In., Front	Brake Area, Rear, Sq. In.	Weight per Sq. In., Rear	Brake Area, Total, Sq. In.	Weight per Sq. In., Total	Retarding Force Per Cent	
							Front	Rear
T_1	88.6	27.6	143.0	49.5	....	...	..	..
T_2	88.6	28.5	143.0	60.0	....	...	..	..
T_3	117.4	23.4	166.8	55.7	....	...	..	..
T_4	143.0	21.5	277.4	46.8	....	...	..	..
T_5	64.2	...	119.7	...	183.9	44.5	..	..
T_6	64.2	...	119.7	...	183.9	54.3	..	..
T_7	120.0	...	209.0	...	329.0	39.5	..	..
T_8	128.0	...	209.0	...	337.0	47.5	..	..
T_9	178.5	...	220.5	...	399.0	47.6	..	..
T_{10}	178.7	...	296.0	...	474.7	46.3	..	..
T_{11}	222.0	...	380.6	...	602.6	41.5	..	..
T_{12}	222.0	...	380.6	...	602.6	49.8	..	..
T_{13}	222.0	...	380.6	...	602.6	56.5	..	..
T_{14}	222.0	...	417.0	...	639.0	62.6	..	..
B_{15}	307.0	...	294.0	...	601.0	...	..	..
B_{16}	307.0	...	294.0	...	601.0	...	..	..
B_{17}	450.0	...	291.0	...	741.0	...	..	..
B_{18}	450.0	...	291.0	...	741.0	...	..	..
B_{19}	346.0	...	344.0	...	692.0	...	..	..
B_{20}	401.0	...	401.0	...	802.0	...	..	..
T_{21}	151.0	...	151.0	...	302.0	37.7	50	50
T_{22}	183.0	...	244.0	...	427.0	45.6	30	70
T_{23}	183.0	...	244.0	...	427.0	54.8	30	70
T_{24}	208.0	...	263.0	...	471.0	56.0	22	78
T_{25}	264.0	...	355.0	...	619.0	48.4	30	70
T_{26}	264.0	...	426.0	...	690.0	45.2	31	69
T_{27}	192.0	...	426.0	...	561.0	64.7	25	75
T_{28}	196.0	...	420.0	...	616.0	113.6	25	75
B_{29}	183.0	...	244.0	...	427.0	35.8	30	70
B_{30}	180.0	...	371.0	...	551.0	35.3	25	75
B_{31}	180.0	...	371.0	...	551.0	42.4	25	75
B_{32}	280.0	...	355.0	...	635.0	32.4	50	50
B_{33}	355.0	...	852.0	...	1,207.0	24.8	43	57
B_{34}	373.0	...	373.0	...	746.0	35.5	48	52

satisfactory results, a suitable value for the product of these three factors can be obtained.

It is interesting to note the variation indicated by the different factors for brake capacity as referred to life. Generally, the custom has been to base this on the ratio of area to weight; however, when the energy of the vehicle is related to the area, the effect of velocity is clearly indicated as an important factor. In these calculations, it was assumed that the vehicle would be stopped at a rate of 15.35 ft. per sec. per sec. from the maximum speed as given to obtain BL_s. To obtain BL, it was assumed that the vehicle would be retarded from the maximum speed to a speed of 20 m.p.h. and held at this speed on a 10 per cent grade 1 mile long. There is no intention to imply that these figures are correct or the ones which are best to use; they were selected at random to illustrate the calculations.

In the discussion of the formula, the result was indicated in foot pounds per square inch, but it seems that foot pounds per square inch per second gives a better result for comparative purposes.

It is evident that the relations of net area of the brake lining, A, to the product of G, V and W, is comparable to the energy per square inch per second for control down hill, but does not agree with the requirements for stopping. No attempt will be made to discuss all the implications arising, but merely to point out that the method properly allied with experimentation may produce something of value.

In Table 2, interesting figures are given for trucks and buses. Insufficient data were available on these vehicles to obtain figures comparable with those in Table 1.

Little advantage would be gained by selecting individual figures in Table 2 for comment. Obviously, the data are incomplete and it is quite probable that with complete information calculations made on some basis similar to the one suggested would clear up many apparent inconsistencies and might develop others.

No proposal is made herein to establish par values for any of these variables, as it is obvious that such action would be restrictive and harmful. Possibly, if the method or some alternative which can be developed is practical, an experience will develop which will establish desirable limits for them which will be valuable.

Fuel-Oil Supply Ample for Wide Diesel Use

WHAT of the future trend in fuel-oil prices and availability? Many engineers and economists, in all good faith, have predicted dire results if the Diesel comes into general use. They have visualized a shortage of fuel stocks and a significant rise in price, both of which are serious enough to scare away many luke-warm adherents.

What are the facts? I have been assured by petroleum refiners that there is a real abundance of fuel oil and crudes and no prospect of a shortage. In fact, the only basis for the alarmist theory is the old wartime situation when conservation was a matter of national emergency and when all available materials were converted to national defense.

To settle the remaining doubts that may exist let me quote from Report V of the Federal Oil Conservation Board to the President, October, 1932. The following is from page 27 on the effect of technological advance in petroleum refining:

"However, the effect of the use of the cracking process on the demand for crude petroleum is indicated by the fact that 17,181,000 bbl. of cracked gasoline were produced during 1931. To produce this quantity of straight-run gasoline would have required 716,200,000 bbl. of crude oil of the average quality run to stills during that year.

"The volume of crude oil not needed because of changing conditions and refinery technique is equivalent to 84 per cent of the total production of crude oil in the United States during 1931. This effect of the cracking process upon the production of crude oil is difficult to evaluate in concrete terms. However, it is evident that a vast amount was held in underground storage which otherwise would have been produced rapidly to meet a real demand, and the economic structure would have been different than under existing conditions."

The probable course of fuel-oil prices will depend upon the growth of Diesel transportation. If we use reasonable figures and assume that for some time to come the growth will be in the direction of heavy-duty equipment, it is safe to say that price levels will be unchanged. This is the opinion of petroleum refiners. Of course, at that stage we may expect the general imposition of a fuel tax which will bring the wholesale prices of gasoline and fuel oil closer together. Even then there should be a spread of at least 2 cents per gal. between the two fuels.

Before leaving this important section of fuels, we should emphasize the role of distribution. At present, there is no machinery for the general retailing of fuel oil. Now and in the future fleet operators will continue to buy in tank lots at favorable contract prices.

The smaller truckers probably will have to buy from 50 to 150 gal. at a time at a somewhat higher price. There is no provision whatever for the small user, and, until the situation changes, the fleet operator must set up his own refueling facilities. . . .

The design of the engine and operating conditions exert a profound influence on Diesel-engine maintenance. So far as European experience is concerned, one can take his pick of the results. Some quarters show glowing reports; others, not so good.

Perhaps the most widely quoted and certainly most scholarly report on the subject is entitled Oil Engines in Passenger Transport, by H. F. Haworth and P. E. Biggar, of England. It is well worth reading. The authors conclude that the Diesel engine requires more maintenance and have established a figure 47 per cent greater than that for the gasoline engine. Moreover, they find that the depreciation rate is higher for the Diesel, so that the combined weighting of added maintenance and depreciation is set at 60.5 per cent above gasoline-engine practice.

Excerpts from a paper presented by Joseph Geschelin at a meeting of the Cleveland Section.

Airplane Vibrations and Flutter Controllable by Design

By J. A. Roché

U. S. Army Air Corps, Materiel Division

THE purpose of this paper is to pass on to airplane designers the things that have been learned in the last year about flutter and vibration of structures to which control surfaces are attached in order that, benefiting by all experience available, this great source of danger in new designs may be controlled.

Test pilots also should be interested in this subject because it may help them in deciding proper action when a case of flutter is encountered and to recognize vibrations which may lead to destructive flutter.

The present-day methods of stress analyses, imperfect though they are in certain respects, and the design load-factors in current use are adequate to provide all the strength needed in airplane structures for flight in rough air, and for all necessary maneuvers. A review of structural failures in the air reveals the fact that a resonant vibration was in nearly all cases responsible.

WHEN a new high-performance airplane is brought out, the chief concern is not its strength, nor its performance, nor even its stability, or spinning characteristics, for these qualities can be determined with fair accuracy, but whether it will be free from flutter, buffeting, and vibrations in all attitudes and speeds within its design range.

A specific review of destructive flutter cases within our experience would prove instructive, interesting, impressive and would serve as a good foundation for the progress of the flutter problem, but this must be omitted for lack of space and other good reasons. It is likely that each designer and pilot possesses recollections of his own which will serve the same purpose.

[A paper read Sept. 4, 1933, at the International Automotive Engineering Congress, Chicago, and Constituting U. S. Army Air Corps Technical Report No. 2861, Materiel Division.]

The main factors which determine the potentiality of a resonant flutter are as follows:

(1) The character of the airflow around the airplane as affected by drag distribution, speed, power, and air bumps.

(2) The rigidity of the structures, rigging, controls, and fittings.

(3) The design of control surfaces as affected by shape, aerodynamic balance, and mass distribution.

Character of Airflow

The character of airflow around an airplane can be described as follows: Fig 1 shows schematically four kinds of disturbances, each of which results in vortices emitted at more or less definite frequencies for each attitude and speed of the airplane. Fig. 2, which represents the familiar lift and drag coefficients of the airplane, assists in showing the relative strength of the disturbances. The disturbances denoted by the letter *a* in Fig. 1 are the tip vortices caused by induced drag. Their power is:

$$Hp._{ind.} = \frac{C_{ind.} \times AV^3}{0.96} = \frac{1}{3V}\left(\frac{W}{S}\right)^2 \qquad (1)$$

These vortices are parallel to the direction of flight and do not impinge on the structures or surfaces of conventional airplanes. They are continuously leaving the wing tips and cannot give impulses to them; therefore, they may be omitted from further consideration.

The disturbances denoted by *b* in Fig. 1 are those due to the propeller slipstream. They are very complicated. They contain energy equal to the power output of the engine. A definite frequency equal to the number of revolutions per minute of the engine times the number of propeller blades is felt for some distance aft of the propeller. This frequency will vary from 3000 to 7500 cycles per min. Perhaps 10 per cent of the engine power could be recuperated from the wake by a resonant structure, such as the fin or the stabilizer, but these structures have much lower natural frequencies and fortunately do not seem to respond to this slipstream energy as evidenced by the fact that most cases of destructive flutter are independent of power. In fact, the slipstream scavenges some of the wing and fuselage disturbances so that buffeting is felt on certain airplanes only in the power-off condition. The slipstream impulses may, however, set up vibrations in the tie rods of wings and tails.

The letter *c* in Fig. 1 represents the vortices in the wake of the wing, which contain energy consumed by the profile drag of the airfoil, and we have:

$$Hp. = \frac{C_{prof.} \times AV^3}{0.96} \qquad (2)$$

This power may be quite large, particularly in maneuvers at high speed and at high angle of attack. It is greater for thick than for thin wings at low angles of attack. The portion of the power liberated near the root of thick wings is relatively larger than outboard. Much of this energy will impinge upon the horizontal tail surfaces. Hence, the conception of "buffeting," brought out after the famous Meopham accident.

Buffeting occurs in most low-wing airplanes, but not necessarily to a destructive degree if resonance with the structure does not occur. The intensity of this energy may be materially reduced or the regularity of its frequency may be spoiled by the use of well-designed fillets between the upper surface of the wing and the fuselage, or by reversing the trail portion of the wing near the root, and by other flow-straightening devices. The frequency of this energy is not known precisely, but certain rough rules may be used to estimate it. Karman has shown that these vortices are spaced approximately five times the width of the wake, *W*, as indicated in Fig. 3.

The wake width can be measured roughly with the use of smoke, and perhaps with suitable stroboscopes, or high-speed moving pictures, the vortices could be seen and counted. Thus, a thick-wing airplane traveling at a speed of 300 ft. per sec. may have a wing wake 1 ft. thick at the root; the frequency of the vortices leaving the root is approximately 3600 per min. At low speed, say 125 ft. per sec., the wing wake may be 5 ft. thick and the frequency is 300 per min. The natural frequency of tail structures is within this range; hence, the very common occurrence of tail flutters.

The letter *d* in Fig 1. represents the turbulence due to parasite resistance of the fuselage, the cockpits, windshields and the like. It can be evaluated in a manner similar to that shown for the other disturbances, but nothing definite can be said about the frequency of the vortices arising from this type of drag. If their frequency concurs with that of the wing rollers, no good can come of it. This energy may be reduced by cleaning up the lines of the airplane and retracting the landing gear. Instances have been noted where airplanes suffered destructive flutter with the gear out at high speed, but gave no trouble at still greater speeds with the gear retracted.

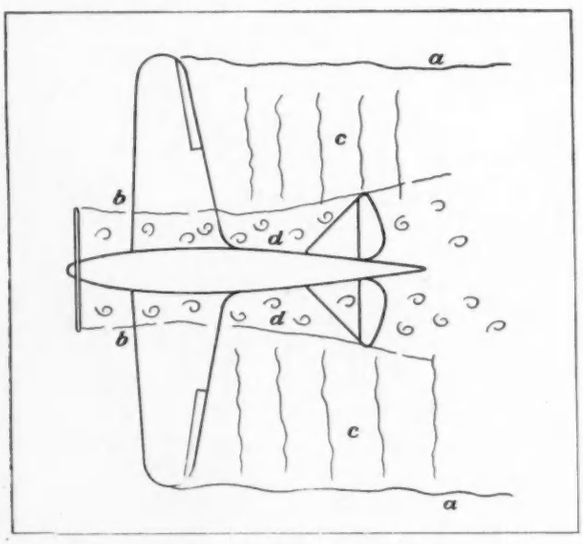


Fig. 1—Character of Airflow Around an Airplane

Each of the disturbances *a*, *b*, *c* and *d*, results in vortices emitted at more or less definite frequencies for each attitude and speed of the airplane.

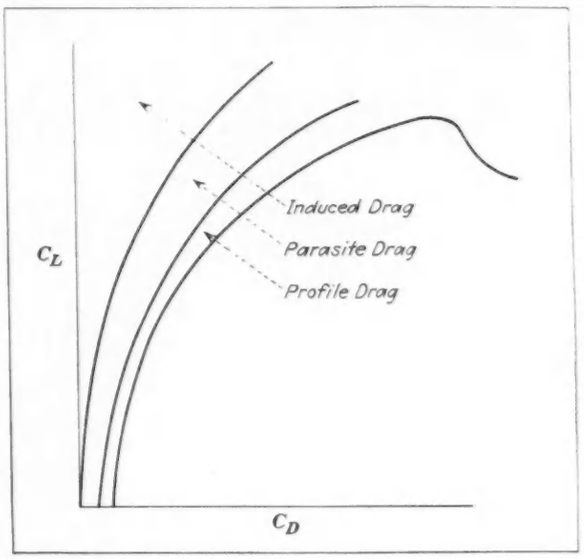


Fig. 2—Curves Representing Lift and Drag Coefficients of an Airplane

The curves indicate the relative strength of the disturbances *a*, *b*, *c* and *d*, shown in Fig. 1.

It is believed that a fairly efficient vibrator of 1-hp. capacity having adjustable frequency will suffice to cause failure in a short time in most current airplane structures, very much as fuel-tank vibrators point out the weak points in tanks. The foregoing aerodynamic impulses contain far greater power and, therefore, are capable of destroying an airplane structure in a few seconds, so that the time available to change the mode of flight after a flutter is noticed is very short indeed.

The airflow about oval tie-rods is such as to cause them to vibrate most violently when they are either at zero angle of attack to the relative wind or at an angle above their burble point. To minimize wire vibration it is therefore important that they be set at some intermediate angle of attack, neither parallel to the chord nor to the thrust line. The relative wind at any point may be determined, roughly, by flying the airplane at various steady speeds with wool threads attached at intervals along the tie rods. A fluttering tie rod has a short life; hence, the present requirement for double tie rods, if such are used at all, below the wings over the front spar and in the tail bracing on Air Corps airplanes.

Rigidity of Structures

Until rather recently the rigidity of airplane structures was not studied as to its relation to flutter. The conception of rigidity expressed itself as deflections under steady loads or coefficients of torsional rigidity for wings and fuselages. These quantities were carefully measured in static tests or determined by laborious least-work computations, filed and forgotten.

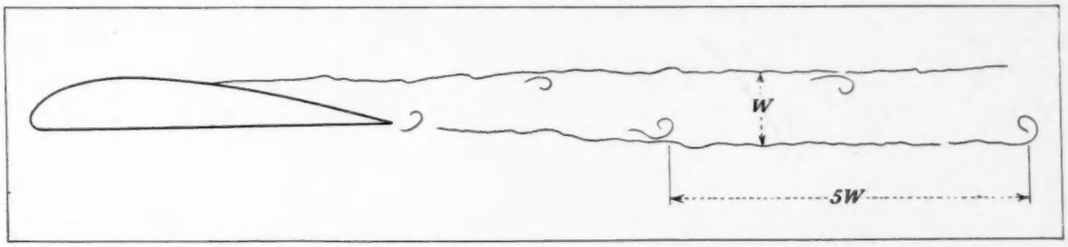


Fig 3 — Diagram Illustrating That Vortices in the Wake of the Wing Are Spaced Approximately Five Times the Width of the Wake

Rigidity as associated with flutter is best expressed by the natural frequency of the structure or member. Each structure and member has several degrees of freedom, of which only one or two are likely to prove troublesome. A method has been placed in use at Wright Field by Messrs. Weaver and Stitz to measure the lower frequencies and the types of motion corresponding to them by the application of a controllable-frequency vibrator which is attached successively at the various points of the airplane which are suspected of likelihood to flutter. This instrument has been applied to tie rods, wing tips, engine mounts, fins, stabilizers and fuselages. A surprisingly large amount of data on natural vibrations has been collected in a few months.

Fig. 4 shows the set-up of the instrument, which consists of a Scotch-yoke-type vibrator driven through a flexible shaft by a variable-speed electric-motor; a gearbox, which is used to secure a greater range of frequencies with ample power and fine control; and an airplane tachometer, which indicates the frequencies. When the vibrator is adjusted to give impulses corresponding to the natural frequency of the part to which it is attached, an unmistakable oscillation of large amplitude results and the system tends to maintain a constant speed. A good deal of additional power is required to operate the vibrator above this hump speed.

Some of the general facts discovered to date are as follows:

(1) Wood wings of the cantilever type can be vibrated in torsion and in bending.

(2) Metal wings are distinctly more rigid in torsion and vibrate preferably in bending.

(3) Tie rods vibrate at frequencies determined by their mass, length and tension, and a knowledge of their frequency permits the accurate computation of their tension.

(4) Fuselages prefer to vibrate in torsion, rarely in lateral bending and not at all in vertical bending.

(5) While determining the natural frequency of structures, it is possible to locate visually the axis of motion.

(6) The natural frequency of airplane parts is little affected by air loads or airspeed. Several experiments on wings and fuselages show vibrations at the same frequency in flight and on the ground. Wires, of course, take up frequencies proper to their flight loads.

(7) Most of the interesting frequencies of tail surfaces, wings and fuselages, can be measured without the use of special suspensions. The airplane may rest on its landing-gear wheels and tail wheel.

Frequency Is Constant

The frequency of structures appears to be constant and independent of amplitude up to a certain point. A reduction of frequency must, however, be expected when the amplitude of motion or the air loads cause sufficient deflection to slack the counter-wires or to cause wrinkles to appear in the stressed skin shells. It can be shown mathematically that the rigidity of a wire-braced structure is distinctly reduced the

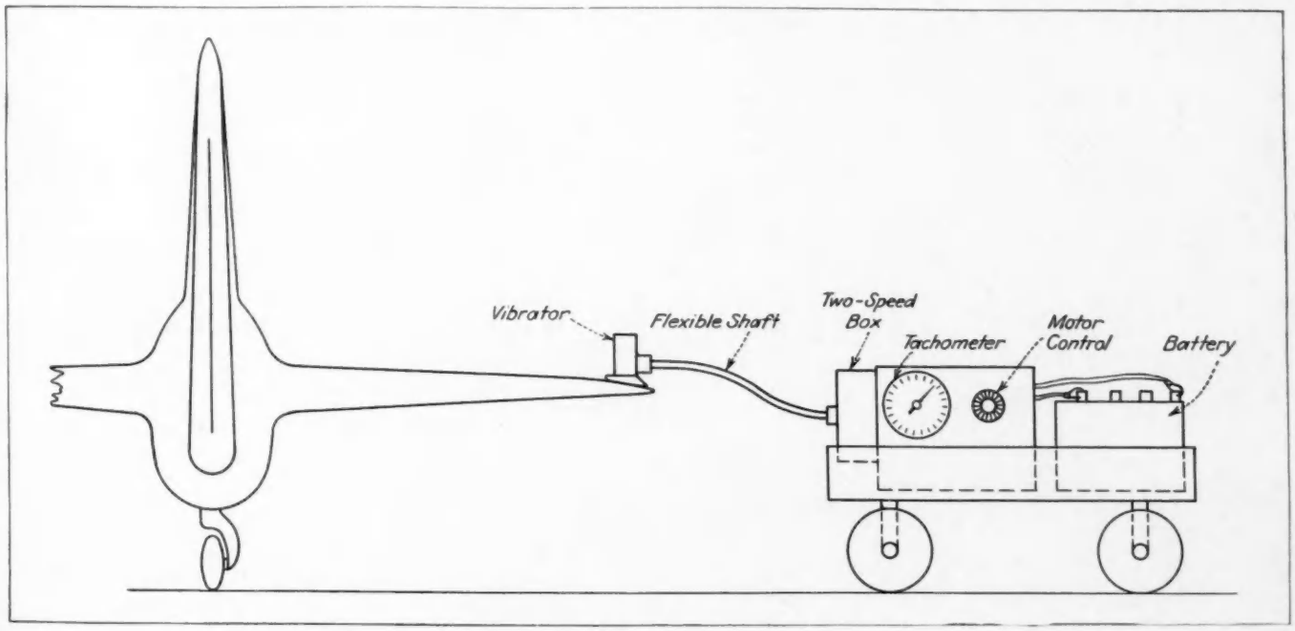


Fig. 4—Controllable-Frequency Vibrator

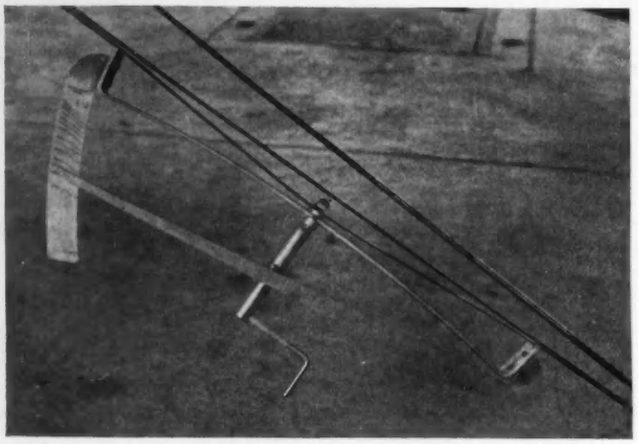


Fig. 5—U. S. Army Air Corps (Materiel Division) Tensiometer in Use

moment the counter-wire becomes slack. A similar proposition is probably susceptible of proof in the case of stressed skin shells when the wrinkles appear.

The Air Corps now controls the rigidity of airplane structures, in cases where it is suspected to be necessary, by specifying a minimum frequency of the order of 600 to 1200 cycles per min. In the case of engine mounts, a frequency slightly above idling speed seems desirable. Powerplant frequencies, either of the order of the number of revolutions per minute or the total number of explosions per minute, find resonance in propeller blades and cause trouble there. Oscillations normal to the plane of radial engines seem particularly destructive to propellers and engine accessories. The trend is, therefore, toward the elimination of freedom in these directions and the allowance of angular motion—controlled by the hysteresis of rubber cushions—about the crankshaft axis only.

The designer obtains the desired frequency by skillful attention to details. A weight increase is often necessary, but in no wise to the extent of the rigidity gained. Eccentricities in members and joints must be carefully avoided. Types and dimensions of wing bracing which give minimum deflections in all directions must be sought, even at a sacrifice in weight. Cockpit edges must be well reinforced; gusset plates must be used to transmit torsional shear around openings as directly as possible. Play in all joints of structures and control systems must be eliminated. The initial tensions in wires must be carefully adjusted to avoid their slackening during any normal flight maneuver. An arbitrary requirement for high margins of safety as called for in Department of Commerce Bulletin 7-A reduces deflections but has the effect of lowering the frequency of the wires, which is distinctly undesirable. A more rational requirement in this particular is set up on page 210 of vol. 1 of the Air Corps Handbook of Instructions for Airplane Designers.

Three Kinds of Tensiometers

The Air Corps has developed three types of tensiometers which are used experimentally and in the field activities to check initial tensions. Fig. 5 shows the spring-beam type in which the deflection of a calibrated spring is matched against the deflection of a measured length of the tie rod. Fig. 6 shows the vibration type used in determining frequencies from which tensions are computed. Fig. 7 shows

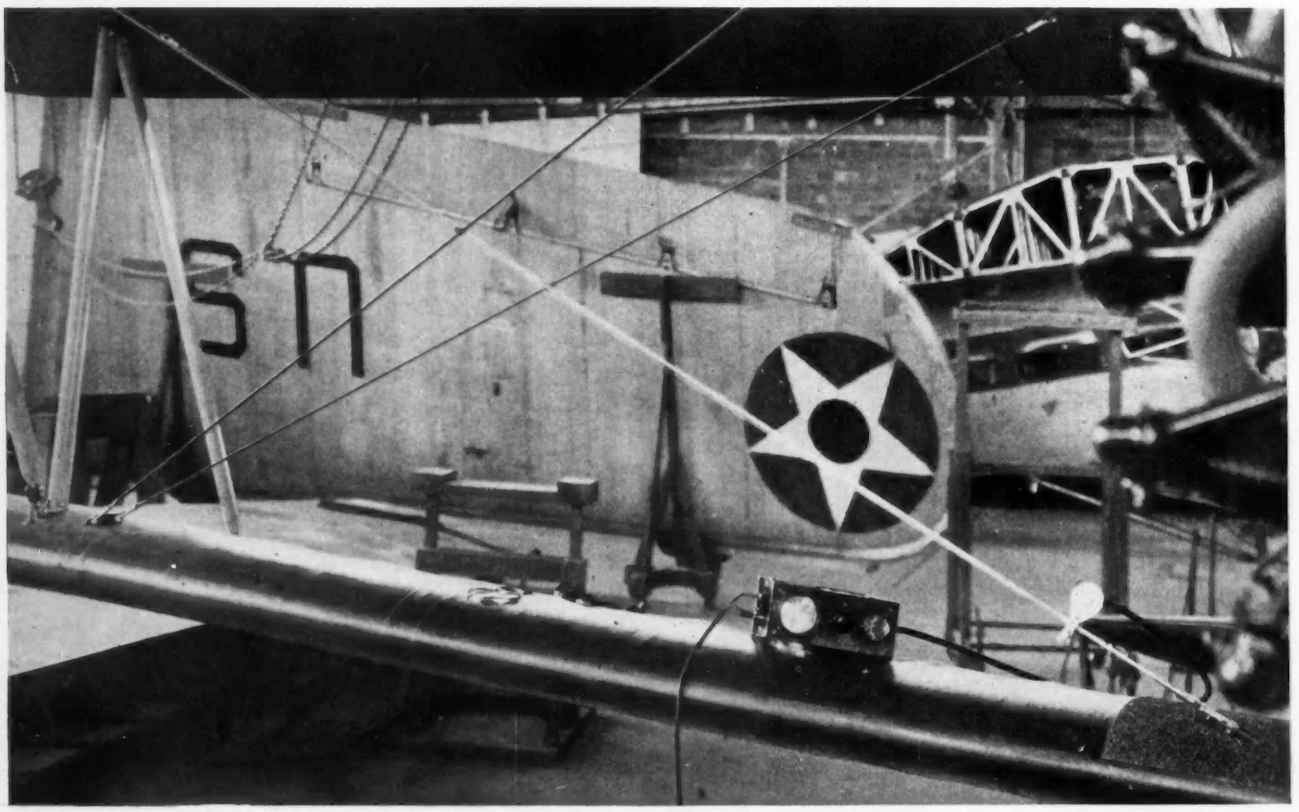


Fig. 6—Vibration Tensiometer in Use on Airplane Wire

the acoustic type in which a portion of the wire is selected of of such length as to emit a standard note, the load being a function of the length read on the frame of the instrument.

Design of Control Surfaces

A large number of flutter cases have been cured by redesigning a control surface and, to date, no case of flutter has failed to be cured by such redesign. It can be inferred therefrom that, while perfect design of control surfaces may not prevent flutters regardless of the character of airflow and the rigidity of structures, it may be the most important factor and it is certainly the most convenient one to work with before attempting the others.

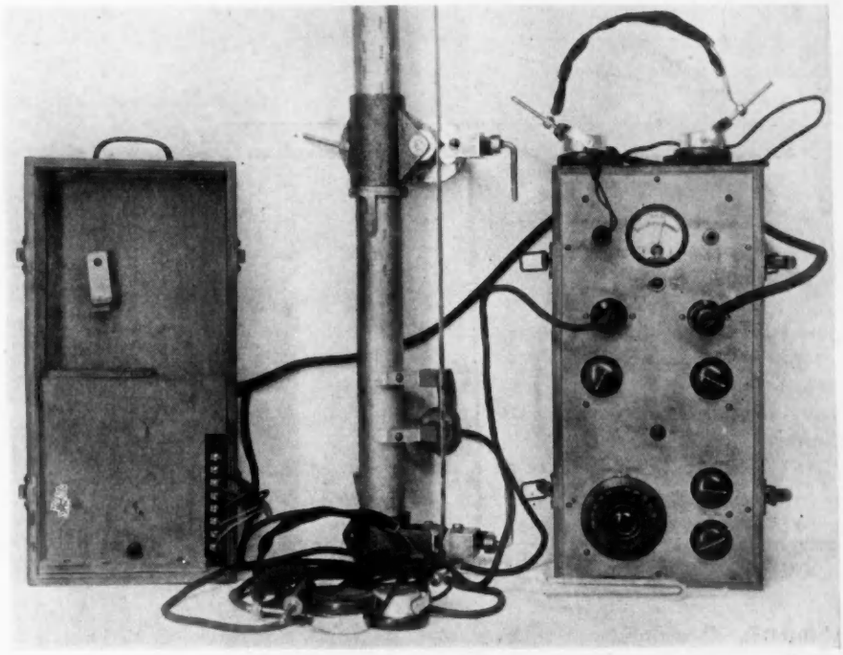


Fig. 7—Complete Acoustic Tensiometer

The principle of design recommended consists in keeping the control surfaces as light as possible and in dynamic balance about their hinge and the natural axis of their supporting structure. These two precautions will prevent the lag of the control surface, which induces aerodynamic forces on the surface preceding it and on itself, thus increasing the elastic deflections at each oscillation. That the lag of ailerons was responsible for the wing flutter of Fokker airplanes was discovered more than ten years ago at the University of Amsterdam, Holland, whence came the suggestion that ailerons be statically balanced by placing lead in the outboard aerodynamic-balance portion. This absolutely corrected the difficulty. The recent English speed-record airplane carried a static balance weight on its rudder, probably to correct alarming flutters experienced in previous flights. Static balance, however, is not necessarily sufficient to prevent control-surface lag and it only does so when it is located in a portion of the surface where it gives the required dynamic balance. For instance, a static-balancing mass located between the elevators ahead of their hinge will suffer no motion or acceleration when the fuselage twists or the stabilizer bends; therefore, no corrective force tending to prevent lag will result.

A control surface is in dynamic balance only when an oscillation about the axis of natural oscillation of its supporting structure does not produce rotation of the control surface about the hinge line. This condition will be satisfied when the mass products of inertia of the control surface are equal to zero.

Consider the case of a rudder, Fig. 8, *YY* being the rudder-hinge axis and *XX* being the natural axis of the fuselage. Each infinitesimal element in the upper right and lower left quadrants then has a tendency to lag equal to its mass times its perpendicular distances—x and y—to the axes *XX* and *YY*, while the elements in the other two quadrants have a tendency to cause rotation of the rudder in the opposite direction. The integrated sum of these products constitutes the product of inertia of the rudder. Its value may be adjusted by eliminating or lightening the construction as much as possible in the upper right or lower left quadrants and by placing most of the material and additional weight, if necessary, in the other two quadrants.

Factors in Dynamic Balancing

Analogous considerations apply to the dynamic balancing of other control surfaces. The following facts should be borne in mind:

(1) The elevator may be agitated by either a fuselage torsional oscillation, or a stabilizer bending oscillation. The location of the natural axis is not very different in the two cases.

(2) A rudder may be agitated by either a fuselage torsional oscillation, or a fin bending oscillation. In the latter case, the large portion of rudder below the flexural axis assists dynamic balance.

(3) In braced-tail groups the fin and stabilizers are so well tied together that the only elastic oscillation which need be considered is that of the fuselage.

(4) In the case of ailerons on cantilever wings, the elastic axis is difficult to locate. An estimate can be made of the effective axis in bending by taking the intersection of the deflected hinge line with the undeflected hinge line, as shown in Fig. 9.

(5) To balance ailerons dynamically for torsional oscillation of the wing will practically require static balance. How-

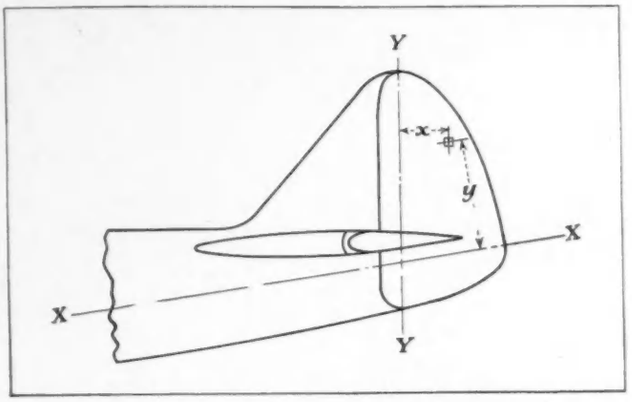


Fig. 8—Diagram to Illustrate Dynamic Balance of an Airplane Rudder

ever, torsional oscillation of metal wings is not so likely to occur as bending unless the skin is weakened by large or numerous apertures.

(6) In the case of externally braced wings, the bracing point may be assumed to be that about which the tip and aileron will rotate.

(7) Perfect dynamic balance is seldom necessary and is not recommended if it must be secured by addition of much dead weight.

(8) The surface must not be overbalanced aerodynamically.

In order that the degree of dynamic balance may be compared between control surfaces at various sizes and shapes, it is necessary to express dynamic balance as a non-dimensional coefficient. This is done simply by dividing the product of inertia, P_I, by the product of weight, W, and area, A, as follows:

$$C_{db} = (P_I / WA) \qquad (3)$$

Note that the product of inertia really represents the shaking power of the control surfaces, while the weight and area represent the size of the surface, so that the coefficient of dynamic balance thus obtained is the ratio of shaking power to size. This index should, in general, be below the value 0.1. Where the speed is great and the rigidity questionable, it should approach zero or even having negative value if it is desired to use the control surface as a damper to possible oscillations.

A sample of dynamic-balance-coefficient computation is given in Table 1 to show the simplicity of the process. Table 2 is given also to show the principal characteristics of flutter cases that have come to our attention recently. Such data should assist designers in acquiring good judgment for avoiding flutters, and it may help investigators into the mathematical theory of flutters to evaluate some coefficients and check their formulas for critical velocity.

Conclusions and Suggestions

In the beginning of aviation, flutter was but a dormant possibility. As performance increased—particularly speed—and as cantilever structures came into use, flutter began to appear; first in wing tips, then in rudders and, recently, all over the airplane. Insufficient attention was paid to flutter until a number of accidents had occurred, each adding its contribution to the data available and its urge to spend time and effort toward flutter prevention. All Government agencies interested in aviation are today contributing their facilities and brains to the understanding and control of airplane flutter.

Table 1—Dynamic Balance of Elevator

Items	Location On Diagram (See Fig. 10)	WT.	+X Axis	+Y Axis	W(X×Y)
Rib-Section No.	1	0.08	3.0	3.7	+ 0.55
	2	0.05	3.0	14.5	+ 2.17
	3	0.05	3.0	22.5	+ 3.38
	4	0.05	3.0	30.5	+ 4.57
	6	0.05	3.0	38.5	+ 5.77
	7	0.05	3.0	46.5	+ 6.98
	8	0.05	3.0	54.5	+ 8.17
	9	0.05	3.0	60.0	+ 9.00
	10	0.03	2.5	65.2	+ 4.90
	11	0.02	10.0	6.5	+ 1.30
	12	0.02	10.0	14.5	+ 2.91
	13	0.02	10.0	22.5	+ 4.50
	14	0.02	10.0	30.5	+ 6.12
	16	0.02	10.0	38.5	+ 7.72
	17	0.02	10.0	46.5	+ 9.32
	18	0.02	10.0	54.5	+ 10.90
	19	0.03	8.5	61.5	+ 15.65
Trailing Edge: Straight Portion		0.23	13.7	29.0	+ 91.70
Trailing Edge: Curved Portion		0.32	9.2	63.0	+185.00
Trailing Edge: Inboard		0.07	10.5	3.0	+ 2.21
Beam Aft of Hinge		0.18	0.35	62.5	+ 39.00
Torque Tube, Outer End		0.40	1.40	3.0	+ 1.68
Hinge: Inboard		0.12	1.0	0.0	+ 0.12
Hinge: Center		0.12	1.0	34.5	+ 4.14
Hinge: Outboard		0.12	1.0	62.5	+ 7.50
64,813 Frame		0.18	2.4	34.5	+ 14.92
64,814 Pyralin		0.07	1.6	34.5	+ 3.86
Metal Cover Leading Edge		0.64	0.5	40.0	+ 12.80
Fabric: 1 to 10 inclusive		0.95	3.5	35.0	+115.50
Fabric: 11 to 18 inclusive		0.90	10.3	30.5	+283.65
Fabric: 19		0.08	9.0	61.0	+ 43.80
Total +X and +Y		5.01	...	...	+912.79

Items	Location On Diagram (See Fig. 10)	WT.	−X Axis	+Y Axis	W(X×Y)
Cloth Leading Edge		0.60	1.7	30.0	− 31.00
Rib-Section No.	20	0.09	1.9	3.0	− 0.51
	21	0.06	1.8	12.0	− 1.30
	22	0.03	1.7	22.0	− 11.22
	23	0.03	1.6	30.0	− 14.40
	25	0.02	1.5	38.0	− 11.42
	26	0.02	1.2	46.0	− 11.05
	27	0.02	1.1	54.0	− 11.87
	28	0.02	1.0	61.5	− 12.30
Beams: 20-21 inclusive		0.29	0.2	9.5	− 5.50
Beams: 22-23 inclusive		0.24	0.2	23.5	− 11.12
Beams: 24-25 inclusive		0.23	0.2	38.0	− 17.50
Beams: 26-28 inclusive		0.23	0.2	53.0	− 24.40
Leading-Edge Cover: 20 to 21		0.59	1.6	9.5	− 9.00
Leading-Edge Cover: 22 to 23		0.45	1.4	23.5	− 14.80
Leading-Edge Cover: 24 to 25		0.42	1.1	38.0	− 17.55
Leading-Edge Cover: 26 to 28		0.42	0.9	53.5	− 20.20
Total −X and +Y		3.77	...	...	−225.14

Items	WT.	+X Axis	−Y Axis	W(X×Y)
Torque	0.56	1.2	1.7	− 1.14
Horn	0.62	1.2	3.0	− 2.24
Bolts, Nuts and the like	0.15	1.2	3.0	− 0.54
Total +X and −Y	1.33	...	...	− 3.92

Total +X and +Y =	5.01	+912.79
Total −X and +Y =	3.77	−225.14
Total =	8.78	+687.65
Total +X and −Y =	1.33	− 3.92
P_I =	10.11	+683.73
Area =	7.43	

$$C_{db} = \frac{+683.73}{10.11 \times 7.43 \times 144} = 0.063$$

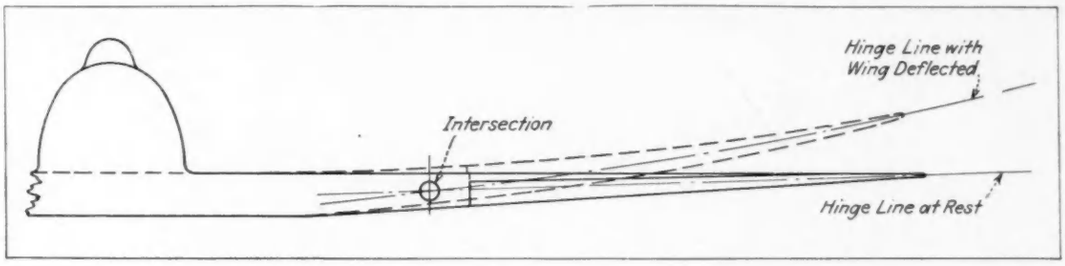


Fig. 9 — Difficulty of Locating the Elastic Axis of Ailerons on Cantilever Wings

An estimate can be made of the effective axis in bending by taking the intersection of the deflected hinge line with the undeflected hinge line, as shown.

The great number of possible disturbances and the wide ranges of frequencies each may have make it impossible to dodge them all by designing the structures to have natural frequencies well beyond those ranges.

Our modern airplane structures are perhaps too perfectly elastic. Some elements possessing hysteresis might have to be placed at the joints of the major parts to absorb some energy and prevent the growth of resonance. Perhaps the airfoils should have flexible trailing edges similar to those of birds and fishes to discourage the formation of powerful and distinct vortices which leave them.

Until the ultimate solution is found, if any exists, the fre-

Table 2—Coefficients of Dynamic Balance for Various Control Surfaces

Airplane and Control Surface	Trailing-Edge Covering	Ballast, Lb.	Weight of Control Surface, Lb.	Center of Gravity Coordinates with Respect to Neutral Point		Area of Control Surface, Sq. In.	Products of Inertia, P_I	C_{db}	Remarks
				X	*Y*				
A—Rudder	Metal	——	41.00	14.83	58.30	4,752	38,208	0.1958	Excessive tail vibration of various speeds. Frequencies—Fuselage, 400; fin, 960.
	Fabric	——	34.70	10.15	54.20	4,608	15,258	0.0953	Gave satisfactory results without perfect balance.
	Fabric	22.50	57.20	3.62	74.70	4,608	0	0	Not tested.
B—Rudder	Metal	——	17.02	4.81	28.68	1,397	2,027	0.0851	Unsatisfactory at 200 m.p.h. Frequencies — Fuselage, 600; fin, 1100.
	Metal	6.0	23.02	2.87	36.06	1,397	1,021	0.0317	O.K.
	Fabric	——	9.05	2.23	26.55	1,426	431	0.0334	To be tested later.
	Fabric	2.25	11.30	1.09	32.20	1,426	0	0	Not tested.
B—Elevator	Metal	——	16.70	4.69	32.38	1,548	2,656	0.1027	Complete disintegration of airplane at 350 m.p.h. Frequencies-Stabilizer, 740; fuselage, 600.
	Fabric	——	9.72	1.28	29.25	1,548	366	0.0243	To be tested.
	Fabric	1.40	11.12	0.55	32.85	1,548	0	0	
C—Rudder	Metal	——	29.50	11.18	38.25	3,466	11,876	0.1160	Buckled fuselage members in coming out of dive at 240 m.p.h. with landing gear exposed. Frequencies-Stabilizer, 1500; rudder, 500; fuselage, 525; fin, 1300.
	Metal	26.70	56.20	3.01	55.30	3,466	0	0	Not tested.
	Fabric	——	21.11	2.81	31.10	3,151	over-balance −67	−0.0010	Satisfactory at all conditions.
C—Aileron	Metal	——	21.50	4.14	106.00	2,995	9,810	0.1521	Left aileron lost in flight.
	Metal	10.00	31.50	1.94	118.00	2,995	5,767	0.0611	No trouble reported.
D—Aileron	Fabric	——	19.60	1.74	131.00	2,966	4,184	0.0719	Caused wing flutter through amplitude of 18 in. Two of crew jumped; airplane landed O.K.
	Fabric	9.50	29.10	0.39	146.20	2,966	154	0.0017	To be tested later.
E—Rudder	Metal	——	27.40	11.13	37.37	3,888	10,986	0.1032	Reported tail vibration at 160 m.p.h.
	Metal	27.10	54.50	3.10	59.10	3,888	0	0	Not tested.
	Fabric	——	26.25	9.63	40.00	3,917	8,715	0.0847	No trouble reported.
	Fabric	20.00	46.25	3.20	58.60	3,917	0	0	Not tested.

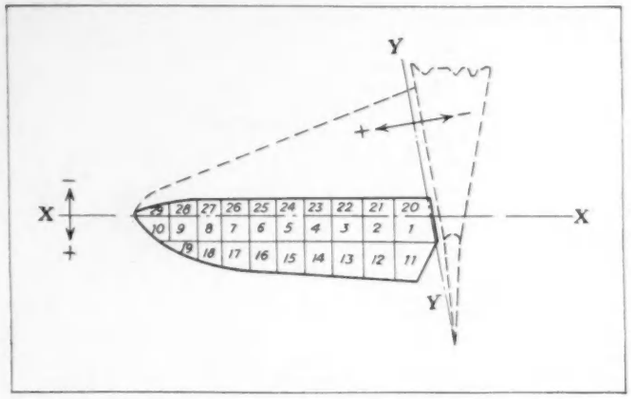


Fig. 10—Diagram to Illustrate Dynamic Balance of Elevator, the Data Pertaining Thereto Being Given in Table 1

quencies of all air disturbances should be studied; the natural frequencies of structures should be measured and, if found low, they should be raised as much as practicable without adding much weight; and the air forces induced by flutter on the hinged surfaces should be minimized by the design of light and dynamically balanced control surfaces.

In preparing for and making test flights, the following precautions should be observed:

(1) Parachutes should be worn; cabins should be open; safety belts should not be so strong as to make forced egress unsafe to the pilot; and intentional egress should be convenient.

(2) At the first sign of flutter the throttle should be closed at once and the airspeed should be reduced slowly, for a sudden change to higher angle of attack at high speed is almost sure to bring on vortices having still greater energy than those which originated the flutter.

(3) All small flutters should be reported and the airplane grounded until they have been investigated or eliminated.

(4) Airplanes should be carefully inspected for tightness of control-surface hinge-brackets and tightness of the whole control system. Cables should have an initial tension of about 100 lb., which should eliminate all play in bearings.

(5) Wire-braced structures should be designed so that wires will not go slack in frequently performed maneuvers. Initial tensions should be checked with some fairly accurate instruments. This will incidently bring out evidence of yield in the structure, unless the change of load can be accounted for by a change of temperature.

(6) In type tests some automatic flutter stops, consisting of sprung weights which latch in place automatically upon the appearance of the flutter, should be mounted on the parts suspected of likelihood to flutter.

Secondary Reference Standards for Knock Testing

THE most direct method of determining octane numbers is by comparison of samples with blends of iso-octane and normal heptane but the cost of the latter prohibits their use in routine testing. As an alternative it is necessary to use secondary standards which incidentally can be made more nearly like normal fuels for spark ignition engines. However, their use introduces another variable in the test method, particularly if various groups of laboratories use different secondary standards. To reduce this factor to a minimum the Standard Oil Development Co. has made available to industry generally its Standard Reference Fuels.

These are made from straight run naphthas to such specifications that they are entirely suitable for use in multi-cylinder engines of aviation, passenger car, bus or truck types. As they are stable products the possibility of change in octane number, gum content or other essential characteristics during storage and use is reduced to a minimum. However, every precaution should be taken to avoid contamination or vapor losses when handling in knock testing laboratories or while actually making tests.

Two Reference Fuels Available

The two Standard Reference Fuels now available have octane number ratings by the "C.F.R. Motor Method" of approximately 44 and 76. For this range the preferred method is to use blends of the two; above 76, C.P. benzene or other suitable anti-detonant may be used.

Calibration curves, in the preparation of which we have had the generous assistance of the members of the American Detonation Committee, are furnished with the fuels. It should be noted that the curves for blends of these with benzene apply only when using the chemically pure variety. Calibration curves for the various grades of commercial benzol would be somewhat different.

Care must also be taken to assure thorough mixing when using benzene blends. Moreover, as the antiknock quality of benzene blends varies markedly with change of engine temperature conditions, it is advisable to limit the use of secondary standards containing benzene. Such blends are, however, very useful for determining whether or not engine test conditions are correct.

Correlating Results

Experience has shown the advantages of using the same reference standards in airplane and road testing as are used in the laboratory. By so doing, correlation of results is more easily accomplished. It is therefore desirable that secondary reference fuels have the same degree of antiknock quality stability with change of engine and temperature testing conditions as the corresponding blends of octane and heptane. This permits blends of two such standards to be used for determining the octane number requirements of engines in service.

As an economic matter it will be necessary to continue the use of secondary reference fuels until methods of manufacture are developed that will make available iso-octane and normal heptane at much lower prices.

Even so there is some advantage in using such secondary standards since they can be made more nearly like commercial fuels than are the primary standards.

—Abstract of paper read by A. E. Becker and C. B. Kass at World Petroleum Congress, London, July, 1933.

What Is Wrong with American Cars?

By L. H. Pomeroy

Managing Director, The Daimler Co., Ltd.

WHILE recognizing that American interest in the 10-hp. type of car is academic at present, Mr. Pomeroy shows reasons why its design warrants close study. He describes an English passenger car that has adequate body capacity and an engine less than half the size of the smallest American engine, one only about one-third the size of the typical six-cylinder engine as fitted to American cars of the $500 to $600 class.

Specific data relating to the English 10-hp. type of car are presented, together with running comment thereon. The statement is made that the case for the 10-hp. type of car rests upon the undoubted and even enthusiastic satisfaction it is giving to a very large number of highly experienced and sophisticated motorists with just as high ideals of what an automobile should be as those in any other country.

Among the subjects touched upon in greater or less detail are: Gear shifting, automatic variable-speed transmission, the Fluid Flywheel, and comments on future passenger-car developments. Rear-engined cars, independent springing, streamlined bodies, weight saving and supercharging are included. In conclusion, Mr. Pomeroy asks whether the American car is to hitch its wagon to the star of top-gear performance for ever in spite of engineering developments which make this wasteful and unnecessary?

I FEEL it my duty to explain that this title was thrust upon me. Not unwillingly I own, as it seemed to make a fascinating subject of research.

May I premise my remarks with two sayings which have a fundamental bearing on the problem, one that "one man's meat is another man's poison" and the other, "de gustibus non est disputandum"—an old Latin tag meaning that in matters of taste there is no argument. For these reasons I do not profess to say what is wrong with the American car, but possibly when I have finished you may be able to say so yourselves.

The Combine with which I am associated caters to a wide range of customers. We build push bikes, motorcycles, three-wheelers with a maximum weight of 900 lb. and cars from 9 hp. or 60-cu. in. engine-capacity and 90-in. wheelbase weighing 1350 lb. up to cars with 330-cu. in. engine-capacity and 163-in. wheelbase weighing 6000 lb., to say nothing of motor-buses weighing 22,000 lb. laden.

We are thus fairly experienced in the acceptable number of cubic feet of body space to suit various markets and what are acceptable performance figures over the whole range of the British automobile industry.

In view of the remarks I have read about the modern American body, it may be of interest to insert in this paper some line drawings of typical English bodies.

Fig. 1 is that of the body on the car used by His Majesty King George V. This is, of course, essentially a state coach; but, in another form, with reduced head room, it is dimensionally the staple car of the best known Hiring Company in the world, in which many thousands of your countrymen have toured Europe in the last few years.

From this we may go to the line drawing of the Baby Austin, Fig. 2, a car sold in large numbers, at any rate from our restricted views of national output.

A size larger is that of the 10-hp. Lanchester, Fig. 3, a very popular car which has caught on this year, and finally that of a 20-hp. Daimler Sedan, Fig. 4, which is regarded in England as somewhat over a medium-sized car.

The popularity this year in England of the 10-hp. type of car is shown by registration of 22,173 new cars of this type in the October-March period of 1932-1933 as against only 4758 in a similar period of 1931-1932; and although even in toto these are small numbers from an American viewpoint, it is not an insignificant matter that these registrations are the biggest on record.

A brief description of this type of car may be of interest, therefore, leading as it does to a technical discussion of certain salient features, which have a decided bearing on the arguments I wish to expound.

American interest in this kind of automobile, I realize, is at present very academic; but I am anxious to show what can be done, and done well, in the way of a passenger car with very adequate body capacity, using an engine less than half the size of the smallest American engine and only about one-third of the size associated with the typical six-cylinder engine as fitted to cars of the $500 to $600 class. If doing this estab-

[This paper read Aug. 30, 1933, at the International Automotive Engineering Congress, Chicago.]

lishes a sort of minimum basis to work from, the rest of the problem may be discussed in terms of differences—which is always helpful in engineering matters.

The 10-hp. type of car has a wheelbase of 93 to 102 in. with a track of 45 to 50 in., thus being essentially a four-passenger car, while its four-cylinder engine of 10-hp. Treasury Rating has a capacity of 60 to 72 cu. in. The top gear-ratio varies from 5.2 : 1 to 5.6 : 1, giving about 4000 r.p.m. The tire size is almost universally 27 x 4.4 in. All these 10-hp. engines are good for about 4000 r.p.m., giving a road speed of about 60 m.p.h., and are used with four-speed gearboxes giving reductions of about 1, 1.45, 2.6 and 4 : 1 on top, third, second and first speeds respectively. The gearboxes are really used in striking contradistinction to the American car in which the engine is made from 50 to 100 per cent bigger than it need be to avoid gear changing.

Under normal running conditions the gasoline consumption is about 30 to 35 miles per Imperial gal., or 26 miles per U.S.A. gal.

The curb weight with a sedan body varies from 2000 to 2300 lb.

These 10-hp. cars give a really excellent point-to-point performance, are exceedingly handy in traffic and are an effective answer to the demand for a comfortable car with a 60 m.p.h turn of speed at a moderate price, which in England varies from £165 to £315.

From the English viewpoint economy in operation is essential. Gasoline is taxed 8d per gal. and compulsory insurance is equal to the horsepower tax, being £10 per year for each item or £20 in all for a 10-hp. car.

Thus taxation and insurance on the basis of 10,000 miles per annum and 30 m.p.g. is as follows:

	Per Annum
Hp. tax	£10. 0. 0.
Insurance	£10. 0. 0.
Gasoline tax	£11. 0. 0.
	£31. 0. 0.

It is impossible to live in England without regarding taxation as a factor in automobile design. For instance, considering an American car of 26 taxable horsepower, and a gasoline consumption of 18 miles per Imperial gal. on the basis of 10,000 miles per annum, we have

	Per Annum
Hp. tax	£26. 0. 0.
Insurance	£26. 0. 0.
Gasoline tax	£18. 4. 0.
	£70. 4. 0.

a sum which, if capitalized at 4 per cent, is approximately £1,750 or, at the current rate of exchange, say $4.70 to the £, the sum of $8,225.

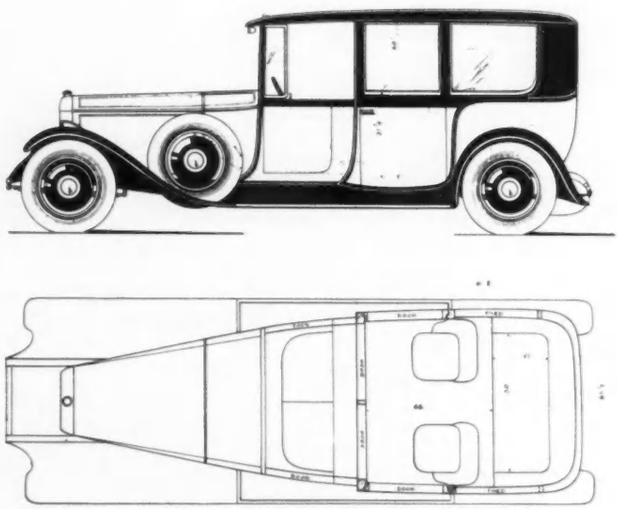
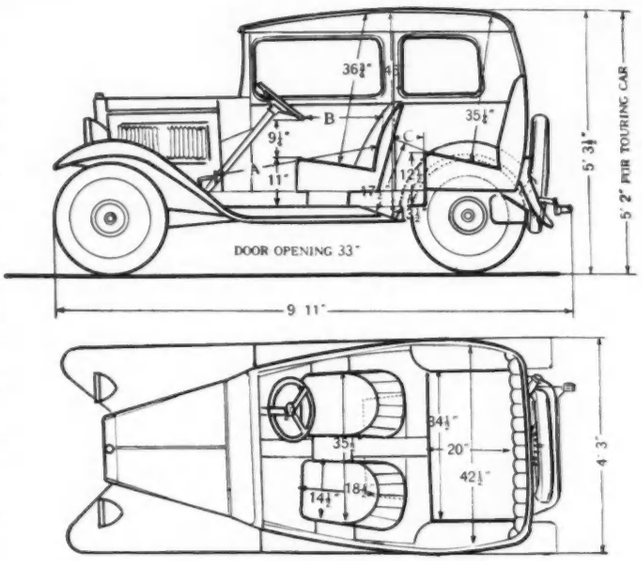


Fig. 1—Body of Car Used by His Majesty King George V



FRONT SEATS ARE ADJUSTABLE

Fig. 2—Line Drawing of Baby Austin, a Car Sold in Large Volume in England

I mention these figures to emphasize the desperate economic urge upon British automobile engineers to develop small-capacity engines of about 2½-in. bore which rely for power output upon their capacity for sustained high revolution speed. Thus, normal engines up to 25 cu. in. per cylinder develop maximum brake mean pressures of about 110 lb. per sq. in. and about 90 lb. per sq. in. at 4000 r.p.m.; that is, a maximum of 30 to 33 b.hp. for a 10-hp. taxable rating. This is approximately the engine speed for a car speed of 60 m.p.h. These engines run up to 4500 to 4800 r.p.m. on the lower gears when required, which is quite often, since the average owner is very proud of the revolution capacity of his engine and the speed the car will attain on second or third gear.

The essential differences between the various makes of engines resolve themselves into variations of valve mechanism and combustion-chamber shape.

Taking the existing makes of 10-hp. cars there are: 1 with overhead valves and overhead camshafts; 1 with overhead valves push-rod operated; 5 with L-heads, and 1 with overhead inlet valve only.

After having battled with the idiosyncrasies of the L-head engine and its funny combustion chambers for many years and now having had intimate experience with the push-rod-operated overhead-valve gear for some three years, I find it difficult to imagine the conditions under which I would revert to the L-head engine. It is not only full of tricks as a power producer, but I am convinced that an engine with

cylinders that are naturally circular in bore rather than unnaturally oval at one end and circular at the other has a profound effect upon the ultimate satisfaction given by the engine in respect to silence, cylinder wear, oil consumption and fuel economy. The overhead-valve engine certainly gives the easiest design from which to develop the highest power and revolution speed from any engine, a virtue which is especially valuable in dealing with a very small engine.

The usual objection to overhead valves is that, to operate at high speeds with reasonable silence, an overhead camshaft must be used. In these days this is not so and a push-rod-operated valve can be made exceedingly silent, absolutely immune from any conceivable expansion effects and to operate with a cylinder unit size of 25 cu. in. at 4500 r.p.m. without the slightest straining after effect.

These engines are successful by reason of the intense study given to the problems of combustion-chamber design, valve operation, pistons and bearings. The British engineer is, of course, favorably situated in that he does not have to design for the enormous temperature range of the United States; but, even so, the inlet manifolds of these little engines are quite liberally hot-spotted. Combustion chambers with overhead-valve engines are about as compact as can be with all due respect to the authorities; the compression ratio is about 6 : 1 for standard fuel, but we take a reasonable amount of care to get the spark plug into the combustion chamber. In fact, so far as overhead-valve engines are concerned, we are back on the old stand of symmetry and compactness.

A few ounces of rubber seem to be equal to quite a lot of higher mathematical combustion-chamber theory in so far as smooth running is concerned.

With regard to the L-head combustion chamber, while I have no evidence, I have a feeling that its days are numbered. For one thing, L-head combustion chambers with high compression ratios are not kind to cylinder-head gaskets and for another valve adjustment necessitate the equivalent of a safe-breaking kit when eight to a dozen valves are stowed away behind inlet and exhaust manifolds, a situation not improved by the manufacturer's instructions to "set valves when the engine is hot."

Valve operation at one time presented acute problems both in respect to noise and valve-spring reliability. Careful cam design has taken care of the noise problem most effectively without recourse to adventitious aids. In fact, my own practice is to use a tappet clearance of 0.060 in.

This, in combination with the cam profile, seems to have overcome most of the unreliability of valve springs arising from valve surge. Valve-stem clearances, both inlet and exhaust, are kept down to a minimum; that is, about 0.001 in. for a valve stem 5/16 in. in diameter, which allows us to lubricate the valve stems adequately without incurring the usual troubles which arise when oil gets near exhaust valves with large stem-clearances.

Valve settings in terms of crank angle are quite normal; that is, inlet opening about 10 deg. before top dead-center and closing about 55 deg. after bottom dead-center, the exhaust opening about 50 deg. before bottom dead-center and closing about 10 deg. after top dead-center. These valve settings are extended in sport-car engines so that there is considerable overlap between inlet-valve opening and exhaust-valve closing for speeds up to 7000 r.p.m.

Aluminum pistons are used in all British engines and the 10-hp. type which I am describing is no exception. I do not believe it would be possible to maintain really high speeds without them and it fills British engineers with amazement that so many American cars have cast-iron pistons. This is at least one thing wrong with more than one American car. But it is inconceivable that this will not soon be remedied now that the true causes of cylinder wear are being discovered and the equivalent of a central heating system inside the cylinder can be supplied in ways less brutal from a bearing viewpoint.

In the present stage of the art, the connecting-rod big-end bearing seems to be the limiting factor to which we are nearest, a problem the 10-hp. engine shares with a good many other types and sizes of internal-combustion engines. Like everything else the reliable feature in a design today is the unreliable one of tomorrow, for the reason that the duty of other items is stepped up and gets ahead of that upon which reliance is based.

In actual use the mortality is very small, yet it indicates the possibilities of still further development. We have found, of course, that the counterbalanced crank with its enormous effect upon smooth running has practically eliminated crankshaft main-bearing wear. We have also found that it has a major effect upon connecting-rod big-end reliability, presumably because of the reduced oil temperature at the big end by reason of the oil passing through the lightly loaded main bearing given by counterbalancing. But while we can run with impunity at 4500 to 4800 r.p.m., prolonged excursions

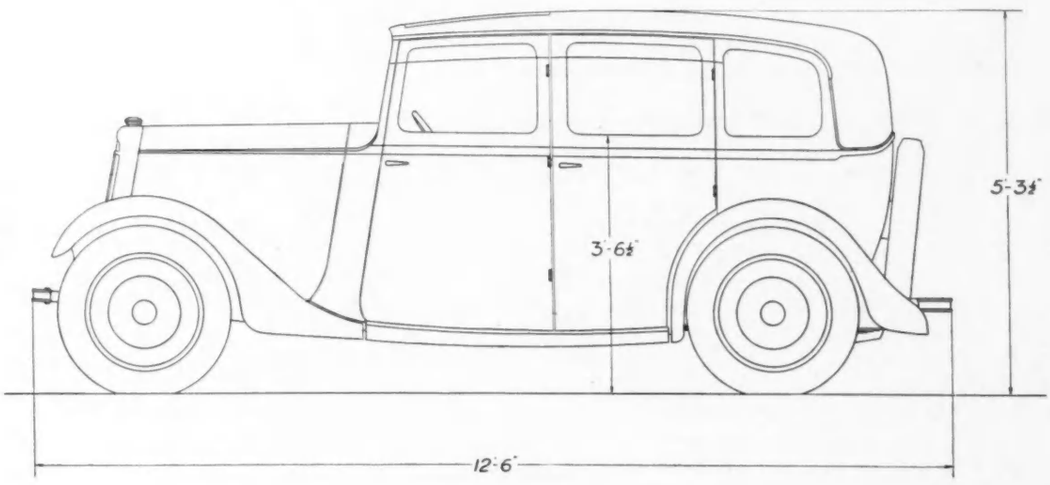


Fig. 3—The 10-Hp. Lanchester, Unusually Popular This Year in England

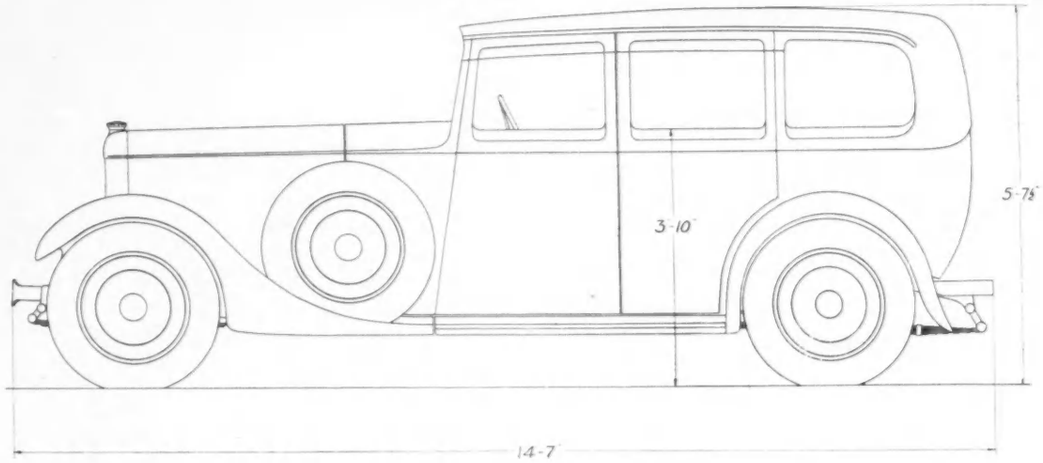


Fig. 4—The 20-Hp. Daimler Sedan, Regarded in England as Somewhat Over a Medium-Sized Car

into the 5000 to 5500-r.p.m. range are not so happy except with aluminum connecting-rods, which are definitely coming into the picture.

It seems about time that this whole business of big-end bearings was rationalized in terms of permissible oil temperature, the grain size of the babbitt where babbitt is used and subsequent grain growth, or in the use of the lead bronzes, which seem very nearly there but not quite.

Fig. 5 gives a horsepower chart of a 10-hp. engine which may be of interest to those studying the possibilities of small-bore engines.

This dissertation on a very popular type of English car is given as an illustration of the English viewpoint in automobile design because it leads to comparisons with its opposite member in the U. S. A.

This, in the lower-priced range, seems to be a car of 56-in. track with a wheelbase of 101 to 114 in. weighing about 2800 lb. and fitted with a six-cylinder engine of about 196-cu. in. capacity. The average revolutions per minute for such engines is about 3300 which, in other words, is the engine speed at 60 m.p.h. on top gear.

It may clarify the argument if these essentials are tabulated.

	U.S.A.	British
Engine	6-cyl.	4-cyl.
Bore and Stroke	3⅛ in. x 4⅛ in.	2½ in. x 3¾ in.
Capacity	196 cu. in.	72 cu. in.
R.p.m.	3,300	4,000
Piston Speed at 60 m.p.h.	2,260 ft. per min.	2,500 ft. per min.
Weight	2,800 lb.	2,200 lb.
Wheelbase and Track	101 in. to 114 in. x 56 in.	93 in. to 102 in. x 45 to 50 in.

Fig. 6 shows the calculated acceleration curves of the above cars and what is obtained for a difference in piston displacement per minute, of 2¾ to 1 if the third gear on the British car is used as intended.

The top gear-performance of these cars is of course very largely in favor of the American car; but I submit that, by paying due attention to transmission improvements which are now being made, notably the four-speed gearbox, the time is ripe for a recast of the philosophy underlying American design. During my own reasonably long residence here, top gear-performance was a *sine qua non*. It is not less so now, but has been coupled with high maximum speeds.

This is indeed an advance, not so much in design as in mental outlook. It took me three years after my return to England before a motorcycle could pass me without my heart contracting in fear of immediate incarceration in jail.

The gist of the matter is as to how far the qualities of performance have been exaggerated at the expense of economy and low cost of upkeep generally, and whether a re-study of these aspects would not result in an automobile which gave a greater margin of profit to the maker and more overall satisfaction to the user. I cannot but feel that it must be difficult to make the typical American car as now designed a profitable article at existing prices.

I submit that a redesign of the typical popular American car on British lines would make the difference in cost of construction essential to insure a profit and would have the sales appeal of economy without sacrifice of anything really worth while in performance.

The British car is designed to be efficient and cheap to run. The American car is the triumph of effectiveness over efficiency. There comes a time when the economics of a motor car has to be studied in relation to other items of the domestic budget and, when everything cannot be had, choices have to be made.

I know it is the fashion to say that with cheap gasoline fuel consumption does not count, but this I doubt when I read of the agitation caused to the American mind by the suggestion of a microscopic increase of automobile taxation. And there is more in it than this. The gasoline which is burnt and does not materialize in performance has to be got rid of in the form of heat through pistons and exhaust valves, to say nothing of water jackets and cylinder walls, and each and every one of these presents its serious problems not only to the designer but to the user.

Given that the gear-changing curse was eliminated, I cannot believe that the average American driver—and in no country is the automobile more a domestic implement than in the U.S.A.—would not feel satisfied with the 10-hp. type of British car. On third gear it has an acceleration of 10 to 30 m.p.h. in about 10 sec. It has a maximum speed of over 60 m.p.h. which, with a calibrated speedometer, can be 70 m.p.h. to the satisfaction of the *amour propre* of the driver and in the interests of his personal safety. It has light axles, is luxuriously sprung, steers beautifully and with the utmost precision.

It also fulfils a very high standard in the very important matter of appearance.

Figs. 7 and 8 show respectively the 9-hp. Riley, and the 10-hp. Lanchester standard sedan.

In the two latter, which are products of my own company, we have succeeded in getting a level floor at a height of 14

in. from the ground by the use of a worm-driven rear-axle. The extra 2 or 3 in. of propeller shaft clearance thus given renders unnecessary the foot wells for the rear seats that are otherwise inevitable.

Fig. 9 shows the side elevation of a 10-hp. sedan body superimposed on that of a typical American body, from which it will be seen that the 10-hp. type of British car involves no sacrifice in the longitudinal aspect of seating accommodation and comfort. In fact, with its narrower track, it looks to the British eye a much more graceful turn out.

There is no reason why the track cannot be increased, although this would call for a slightly larger engine to deal with the increased weight and windage. However, a big gap exists between a 72-cu. in. engine and one of 196 cu. in. —which gives plenty of latitude. In fact, in the comparison I have made, I have tried to establish by force of contrast the basic factors of two different schools of thought, since by going to extremes we can establish a base from which to work.

The logical application to American practice of the arguments set forth probably lies in the six-cylinder edition of the 10-hp. type; namely, the 15-hp. type, the engine being of the same bore, approximately 2½ in., with 4-in. stroke, giving a cylinder capacity of about 108 cu. in. and weighing about 2700 lb.

The case for the 10-hp. type of car rests upon the undoubted and even enthusiastic satisfaction it is giving to a very large number of highly experienced and sophisticated motorists with just as high ideals of what an automobile should be as those in any other country. Making all allowances for the economic aspect of this enthusiasm in a time when saving money is not unpopular among a very large proportion of automobile users, the performance *per se* of the 10-hp. type of car is regarded as of sufficiently high standard to make many people wonder why they should consider anything more as worth having.

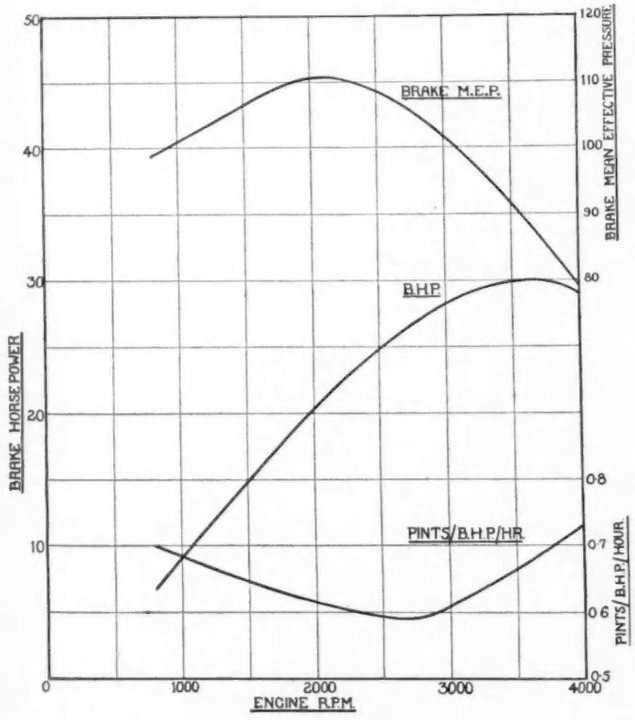


Fig. 5—Horsepower Chart of a 10-Hp. Engine, of Interest to Those Studying the Possibilities of Small-Bore Engines

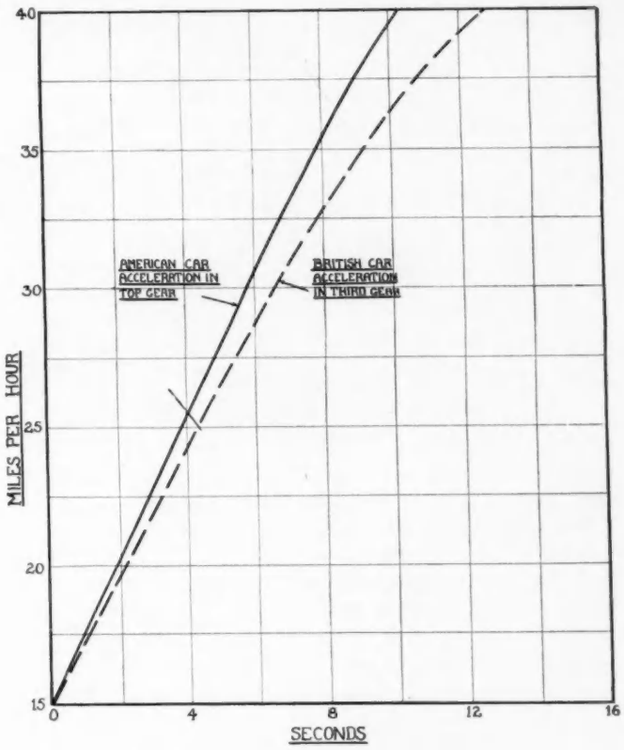


Fig. 6—Calculated Comparative Acceleration Curves of Popular British and American Cars

I have referred to the curse of gear changing and its elimination as the keynote of such a change in design. This problem is included in the larger one of the general handling of an automobile.

A great deal of work has been done in the U.S.A. and in Europe on this problem, but perhaps the limitations of this paper make it desirable that I should refer particularly to the work done with which I have been associated. I would therefore recognize rather than describe or criticize the excellent work which has been done on the same lines by those responsible for the vacuum-operated clutch, the synchro-mesh systems and the Maybach system, also the various free-wheel combinations either alone or with the devices mentioned, all these being systems in production rather than in the developmental or experimental stage.

It has been the aim of inventors to develop an automatic variable-speed transmission ever since the automobile staggered along at the behest of agonized drivers. For thirty years the sliding-gear transmission ruled supreme. As its inventor, M. Panhard, said: "It is brutal but it works." But this must be construed in the light of the words of another cynical mechanical philosopher, Dr. F. W. Lanchester: "It is successful to the extent to which it is not used"—and that is where America stands today.

Like a great many engineers I realized some years ago that the then orthodox transmission system had about seen its day, and was therefore very receptive when, late in 1926, Harold Sinclair submitted an invention which combined a Fottinger hydraulic coupling with an ordinary mechanical clutch, the latter to overcome the difficulties arising from

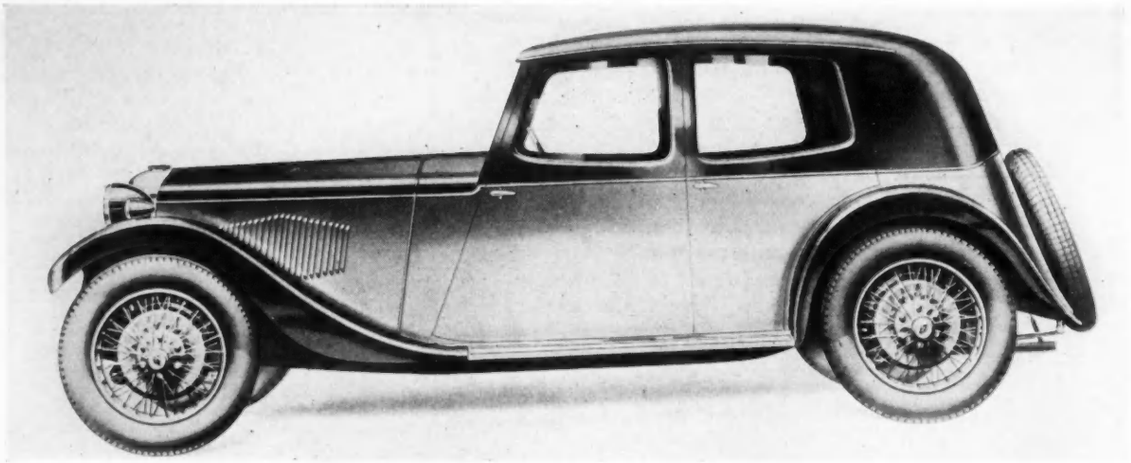


Fig. 7 — The 9-Hp. Riley

slow-speed drag with the Fottinger coupling, which prevented obtaining a free engine and inhibited gear changing.

This looked and was an exceedingly attractive device but still left us with the ordinary sliding gearbox and its manifold problems in noise and easy gear shifting. Further, it added to, rather than reduced, the complexity of design, although, of course, it gave an ease of manipulation which was hitherto unknown.

At this time my company was diligently investigating the matter of epicyclic gears. The essential difficulty in operating an epicyclic gear is that, on the lowest gears particularly, the band tension required to transmit the torque appropriate thereto, (roughly three times engine torque, and on reverse may be seven times), is very high and inherently gives all the problems of a fierce clutch. In brief, a gentle start on a low gear involves the application of a torque to that gear which may be only one-tenth of what it will transmit at full throttle.

It was a realization of the essentials of this problem which led to the Martin patent of combining the Fottinger coupling or Fluid Flywheel, as we had then named it, with an epicyclic gearbox, thus producing the Daimler transmission system, of which there are now some 10,000 applications in successful use. Fig. 10 shows a typical installation.

While the Martin patent covers any combination of Fluid Flywheel and epicyclic gearbox, the particular combination now used in England is that of a Fottinger coupling and a Wilson epicyclic box.

The latter has the property that any gear can be preselected before it is required and the gear engaged only when a pedal is depressed, equivalent to the clutch pedal in an ordinary car. Gear changing is, therefore, a matter of a pedal push only and involves no movements with which the average driver is not familiar. The nature of this epicyclic train is that the tooth speeds are very low and, as a result, the gear noise on the lower gears is, if not silent, such that it cannot be heard. Even with a four-cylinder engine—provided it be flexibly mounted—it is very difficult to know when one is on top gear or a lower gear.

Since the Daimler transmission system was marketed in 1930 we have done a lot of investigation and thinking about transmission systems in general to determine what the next move might be. This survey includes the possibilities of automatic transmission in which the torque control of the car is removed from the driver, but this at the moment seems as if it interferes too much with the liberty of the subject. There are easily conceivable circumstances in which the acceleration given by the ability to temporarily over-run the engine on third speed may be desirable. In any case, such a radical development requires much investigation and sure progress is slow moving.

Any automobile maker is, however, at the moment in a position to give easy gear changing, thanks to the ingenuities of the last few years—some easier than others, perhaps, so that the method of so doing may be regarded as a sufficient problem for the time being.

My own view is that the transmission of the future must at least allow the car to be brought to rest on any gear without disengaging the gear. The enormous convenience in traffic, in parking, in maneuvering in garages and crowded spaces, of complete control by accelerator pedal *only* cannot be appreciated without experience and then reverting to the direct-coupled engine. The application of the vacuum-operated clutch to so many American cars is of course evidence of the claim I am making. Given accelerator-pedal control as a *sine qua non*, the nature of the problem may be defined. All such control involves a coupling between the engine and rear axle with the capacity to disengage when the car comes to rest and re-engage at some predetermined higher speed or one with a slip which varies from 100 per cent to practically zero.

This slipping involves the generation of heat and it is essential that the slipping coupling should be able to stand the slipping condition indefinitely and that this issue be not dodged by limiting the slipping to any particular or limited speed range of the engine. For this reason I visualize the desirable transmission as the combination of a very efficient torque-changing mechanism with a very efficient slipping coupling. This is somewhat paradoxical since an efficient slipping coupling means one that is capable, without injury, of wasting all the energy that under certain circumstances may be transmitted to it, and yet under other circumstances of wasting very little. This is precisely what the Fluid Flywheel can do and does, and now, perhaps, before I go any further, I had better describe the Fluid Flywheel in some detail.

Fig. 11 shows a line drawing of a Fluid Flywheel while Figs. 12 and 13 show the construction of the essential part of the two elements, the driving and the driven. These, it will be seen, are two saucer-shaped discs with many radial webs across the inside or hollow side of the saucer, supported in bearings with no solid connection between them.

If the driven member is regarded for the moment as fixed and the driving member as rotating, it will be seen that the fluid in the driving member is urged outward by centrifugal force and is constrained to return whence it started by returning by way of the cells in the fixed member.

This motion of the fluid is accompanied by profound results. The outward journey causes the fluid to be moving faster at the outside than at the inside, which means that its momentum at radius R is proportionately greater than at radius r. It then impinges upon the driven member and tries to rotate this if the said member is fixed, and actually does so if the resistance offered by this member is less than the force of impingement. The magnitude of the force depends upon the change of momentum of the fluid per unit time. Further, as the fluid moves radially inward its velocity and momentum are being reduced and, as change of momentum per unit time constitutes a force, this reacts upon the driven member and assists in its rotation.

Thus the picture of a particle of fluid in its circuit is, inside to outside a gain in momentum, then an impingement upon a slower-driven member causing a torque to be exerted, then a flow inward still applying a torque to the driven member, then from inside to outside again and so on. The picture of the fluid, if it could be colored, would be like a barber's pole bent into a ring, the pitch of the spirals depending upon the slip or relative speed of the driving and driven members.

The torque which can be transmited by a Fluid Flywheel of small dimensions is somewhat amazing and it is a most interesting fact that for a useful slip-range the diameter of the Fluid Flywheel may be exactly the same as the flywheel it replaces.

The slip curves shown in Fig. 14 are of the Fluid Flywheel used in the Daimler double-deck bus with an engine of 400 cu. in., and in the 10-hp. Lanchester car with an engine of 72 cu. in. The outside diameters of the flywheels are 17.55 in. and 12.35 in. respectively; that is, the normal diameter of starter ring is used, the starter being as close to the crankshaft as possible.

An analysis of the laws of the Fluid Flywheel shows:

(1) That the horsepower transmitted for a given slip and engine speed varies as the fifth power of the diameter of the driven member—or for that matter any other dimension which obeys the law of similarity;

(2) That the slip of a given flywheel at a given speed is proportional to the torque;

(3) That the torque transmitted for a given percentage slip and diameter of driven member varies as the square of the engine speed. The slip percentage is taken on the engine speed, that is, engine speed 1000 r.p.m.; driven-member speed, 500 r.p.m.; slip, 50 per cent.

The Fluid Flywheel follows these laws very accurately, only diverging therefrom mainly because of viscosity effects. The lower the viscosity, the less the slip. The ideal fluid would be one of high density and very low viscosity since viscosity only interferes with free flow and adversely affects matters.

The divergence, however, due to this cause is very small. When one has a mechanism in which its essential characteristics vary as the fifth power of lineal dimension it means that small dimensional differences make large differences in the energy transmitted, other conditions being equal. Thus a relatively small range of diameters covers every conceivable requirement in automobile practice.

It may now be of interest to examine in detail a typical slip curve, shown in Fig. 15.

Driving Member or Engine R.P.M.	Driven Member R.P.M.	M.P.H.	Slip at Full Throttle, Per Cent	Slip at Road Hp., Per Cent
680	0	0	100	100
1,000	851	21.3	14.9	2.5
1,500	1,378	34.4	8.1	2.0
2,000	1,900	47.5	5.3	1.8
2,500	2,420	60.5	3.0	1.5
3,000	2,940	73.5	2.0	1.4

The above figures relate to a car with a 397-cu. in. engine weighing 5500 lb. laden, geared so that at 1000 r.p.m. of the driven member on top gear the speed is 25 m.p.h.

It will be seen that, under level road conditions, the slip varies from 100 per cent to 1.4 per cent and that at 50 m.p.h. the slip is 1.7 per cent; that is, the efficiency is 98.3 per cent.

Under conditions of full torque, that is, accelerating from rest, it will be seen that the propeller shaft, as it were, be-

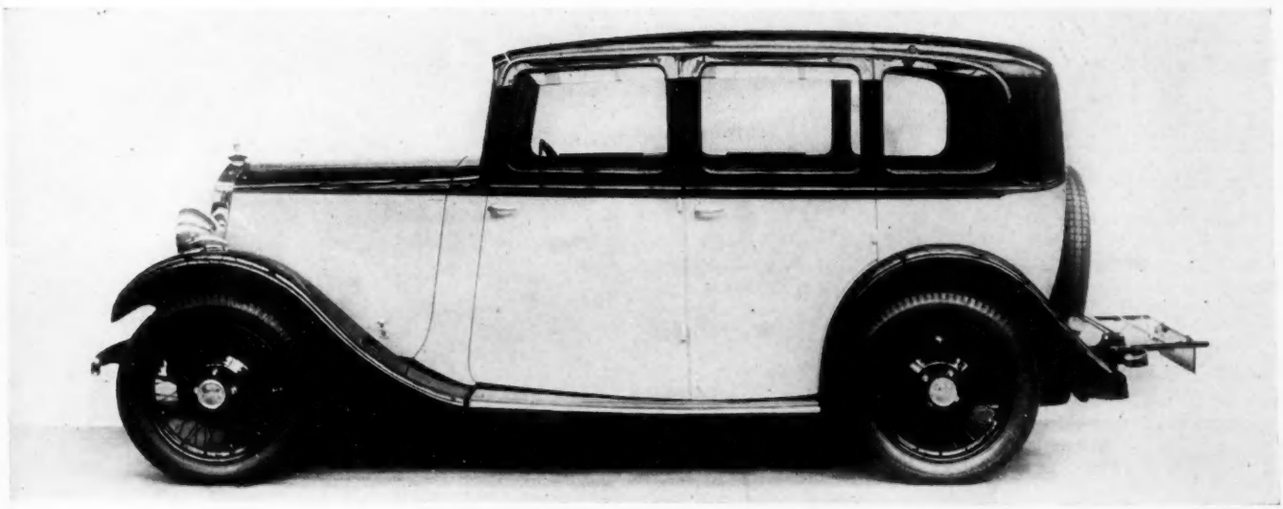


Fig. 8—The 10-Hp. Lanchester Standard Sedan

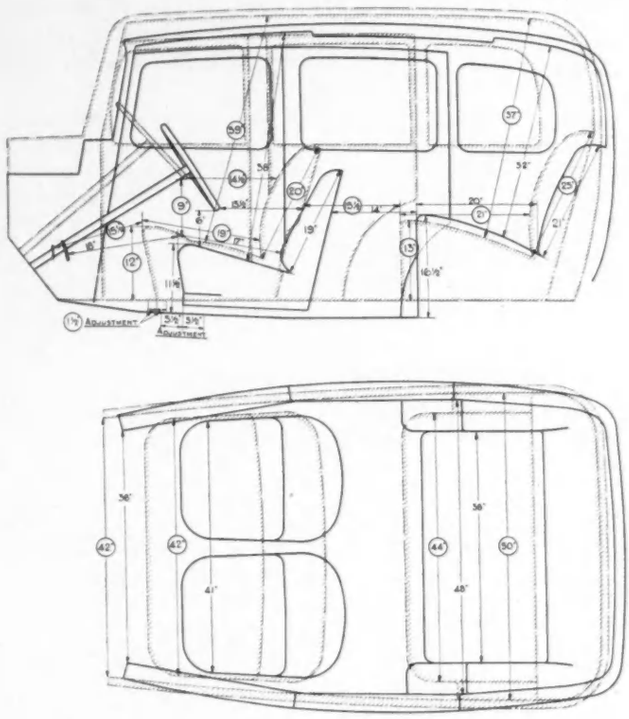


Fig. 9—Side Elevation of Sedan Body of a British 10-Hp. Car Superimposed on That of a Typical American-Car Body

gins to chase the engine but never quite catches up. This of course means a wastage of power and apparent increase of gasoline consumption, and if this were the usual condition of operation it would mean such increase.

In actual fact, either in bus operation or on cars, the difference is so small that, over a series of vehicles, otherwise the same but some with and some without the Fluid Flywheel, the difference in the average of each type is far less than the difference between the average for each type and the best and worst in each type.

I give the following table referring to over 500,000 miles of motor bus operation with and without the Fluid Flywheel on a very hilly route involving eight stops per mile and for tests on a car which was arranged so that the Fluid Flywheel could be cut out at will.

Daimler Buses	Engines—6 Cylinder 97 x 130 Mm.	
	Total Mileage	Ton Miles per Gallon
9 Buses with Fluid Flywheels	293,013	33.2
7 Buses without Fluid Flywheels	260,220	34.3
	Average Difference 3.21 Per Cent	

Lanchester Car	Engine—6 Cylinder 69.5 x 110 Mm.		
	Average Speed	Mileage	Miles Per Gallon
	33.8	63.2	19.25
With Fluid Flywheel	31.6	63.5	19.6
	31.8	63.4	18.9
Average	32.4	63.4	19.25
	34.1	63.3	18.7
Without Fluid Flywheel	31.3	63.3	20.0
	31.4	63.5	19.8
Average	32.3	63.4	19.5
	Average Difference 1.28 Per Cent		

Apart from gasoline consumption is the fact that the slip in a Fluid Flywheel has no effect whatever upon the engine torque transmitted. Otherwise, of course, Newton's third law of motion that action and reaction are equal and opposite would, like Newton's apple, fall to the ground.

There is, however, a secondary effect. The engine speed at the moment of accelerating from rest increases at full throttle to about 500 r.p.m. on what is usually a steeply rising torque curve and the increased torque thus obtained from the engine is transmitted to the propeller shaft in exactly full measure. See Fig. 16.

It will be seen that the top-gear torque from 4 m.p.h. to 15 m.p.h. is increased by the amount shown on the shaded part of the diagram. When allowance is made for road resistance, the improvement is greater than shown, since the gain in effective torque is a net gain.

For this reason the hill-climbing ability at low speeds is always appreciably better with the Fluid Flywheel than without it.

There is not a similar gain in acceleration because of the energy absorbed in accelerating the engine, but there is an improvement.

The degree of slip which has been described obviously raises the question of heat dissipation. I have never felt a Fluid Flywheel on a car after a long run that was anything like as hot as the brake drums. In fact, the casing of the flywheel is usually only hand warm. On the other hand, under test-bench conditions, if slipped 100 per cent at full torque, it has to absorb all the horsepower given out by the engine under these conditions and rises to a temperature of about 350 deg. fahr. in 7 min. This is equivalent to holding a car on a gradient of about 10 per cent by using the Fluid Flywheel only.

Actually, when made of aluminum, and in still air, it dissipates about one-third of the energy put into it at the stalling speed and with this we find no necessity for cooling ribs. This statement is made after experience with 10,000 applications.

There have been examples, of course, of gross abuse, but we have on record no instances of boiling the fluid and, if such have taken place, all is well when it cools down again, which cannot be said of a mechanical clutch when once it has been raised to the nearly red-hot stage.

Before leaving the Fluid Flywheel, a word should be said about the gland to the driven shaft. It will be seen that this shaft rotates at the slip speed only. Its maximum speed is thus about 500 r.p.m. and its normal speed at, say, 40 m.p.h. is about 60 r.p.m., so that it has a relatively easy job compared to the gland in a worm-driven axle.

Finally, as an idling device there is nothing in the world to touch it. It is possible to drive 100 yd. in 5 min.; that is, about 0.7 m.p.h. so that, in competitions in England involving flexibility, a minimum idling speed of 5 m.p.h. is prescribed to give non-Fluid Flywheel cars a chance.

The action of the Fluid Flywheel is as automatic as anything can be. It is in a very real sense a torque valve under perfect control by the driver's foot with no idiosyncrasies which may need correction by adjustment or may suddenly manifest themselves to the embarrassment or danger of the driver.

As has been said, the energy which can be transmitted in a small compass of sizes is remarkable. A Fluid Flywheel of some 8-in. rotor-diameter will transmit the power developed by a motorcycle engine, while at the other end of the scale, 300 hp. can be transmitted at 3000 r.p.m. with an

efficiency of 98 per cent without exceeding the diametrical limits of a normal motorbus-engine flywheel. Its qualities are derived from its powers of converting momentum into force and not from any drag or frictional effects so that increase of speed produces an increase of efficiency. So far as I know it is unique as a coupling between a prime mover and its driven mechanism. It is a result of the fundamental analysis of a problem which should make all engineers appreciate and respect the name of its inventor, Dr. Fottinger.

As mentioned earlier in this paper the Fluid Flywheel is used in combination with an epicyclic gearbox. We spent much money and time trying to use it with a sliding gearbox without success, and I am not optimistic as to the prospects of any such attempts.

While the epicyclic gear seems a mouthful at the outset, one soon gets to like the taste, even as a manufacturing proposition. This matter of manufacturability is very much a process of what the psychologists call conditioning and, judging from descriptions of new gear-changing mechanisms in the U.S.A., the process is well advanced.

The epicyclic gear is a very logical gear from the viewpoint of stress distribution, insofar as the gear itself is concerned. The principal problems lie in its operation. It should not call for any movements to operate it to which the ordinary driver is not accustomed, nor should it involve appreciable physical effort. In this connection it is of interest to observe the popularity of the Daimler transmission system with bus drivers in bus operation involving 4000 gear shifts per day.

The Wilson box offers a very complete solution of the various problems involved, including those of automatic band-adjustment and light pedal-pressure. As time goes on others will naturally arise.

The essential feature we have aimed at is a separation of the variable-torque function of the transmission from the engine by means of an ideally flexible coupling so that the problems of high transmission-efficiency and of heat dissipation can be properly dealt with independently.

I trust it will be appreciated that, in thus somewhat fully presenting the one improvement of the transmission problem

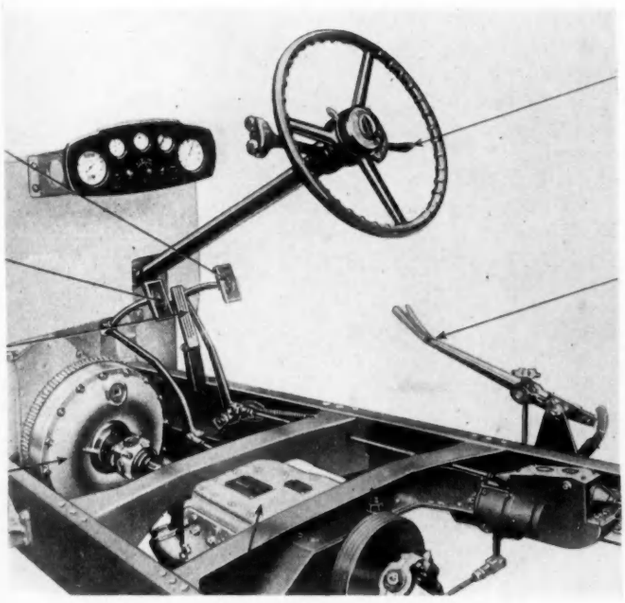


Fig. 10—Typical Installation of the Daimler Transmission System

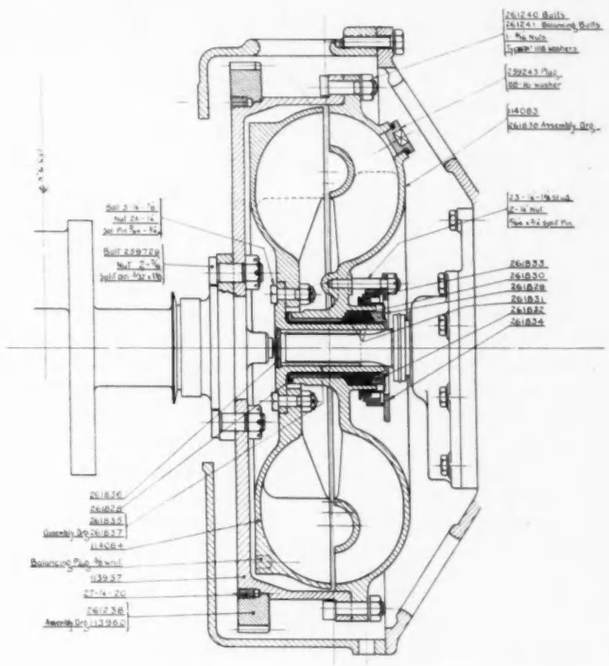


Fig. 11—The Fluid Flywheel

of which I have detailed experience, it is not my desire to suggest that there are no other possibly more complete solutions; but, so far, the ones we have investigated are defective either in efficiency or in convenience of operation.

It seems to me that any automatic variable-torque mechanism has to be selective in its operation to be successful. It must distinguish between the desire for low torque at low speeds, as when idling and high torque at low speeds as when accelerating; otherwise, the effect is that of a compulsory engagement of a lower gear at low speeds, which is undesirable from the viewpoint of smooth operation.

Thus, if the automaticity of the gear operation is a function of engine speed, only the lower gear ratio will come into operation only at low engine speeds. If the automaticity is a function of engine torque—that is, inlet-manifold pressure, then the lower gear ratio will come in when the throttle is opened regardless of engine speed.

The automatic gear to simulate manual operation must:

(1) Give a low gear-ratio over the whole engine-speed range with wide-open throttle.

(2) It must not give a lower gear-ratio at any speed or throttle opening unless it is wanted.

These conditions seem somewhat difficult to realize practically.

These remarks apply particularly to the various variable-torque mechanisms or torque converters which have been developed from the Fluid Flywheel based upon the insertion of a reaction member between the driving and driven members. The function of this member is to alter the conditions of flow of the fluid between the driving and the final driven member, thus giving a torque characteristic in which the torque exerted by the driven member increases as the car speed diminishes, so that the extra resistance produced by climbing a hill causes a slowing down of the engine with an increase in torque at the road wheels.

If the car is accelerated from a low speed, the engine speeds

up just as if with a standard gearbox the lower gear were engaged for every acceleration.

This is not conducive to smoothness of operation. Further, the efficiency of all the torque converters we have examined is a maximum of about 85 per cent as against a 98-per cent efficiency for a mechanical gear. Not only is the maximum efficiency low, but it falls away seriously on each side of the optimum condition.

Earlier in this paper it was pointed out that the use of a Fluid Flywheel involved no loss of torque as between the driving and the driven members. Thus, in a car in which the engine gives a uniform torque throughout its speed range, there is no loss in tractive effort through Fluid Flywheel slip, although there would of course be a very slight loss at maximum speed which would be in the order of 2 per cent in horsepower and possibly ½ per cent in maximum speed. This condition of constant torque does not, however, exist in the torque converter. Not only does the efficiency fall off at speeds above the optimum but the tractive effort is also reduced, which seriously affects acceleration. This fact is recognized in some torque converters by the use of a mechanical clutch to take care of the conditions arising above the optimum speed.

In the foregoing I have suggested that there are two major technical items in the general design of American cars which are susceptible of improvement.

(1) That the size of the engine has been developed out of all proportion to the requirements of rational performance.

(2) That the American school of design is being slow to avail itself of the possibilities arising from considering the gearbox as an essential part of the powerplant to be used as much as desired, not as little as possible.

There would be more excuse for the characteristic American design if the appearance, luxury and spaciousness of the body had been made to correspond with the overwhelming power performance, but such is not the case. High acceleration and high speeds have been made a fetish, while American cars in their various classes are strikingly alike in appearance and cramped in accommodation.

While power performance is of course the be-all and end-all of a racing car, it is a matter of indifference to 95 per cent of the motoring population. I do not mean by this that the public will tolerate a ridiculously low performance, but surely there is a happy medium.

Unhappily, acceleration and maximum speed are expressible in figures to the joy of the publicity departments and, like most statistics, need regarding with caution.

It is very easy for high maximum speeds to get out of scale with the car as a whole. When cars weighing 25 cwt. designed to give a comfortable ride with two up have maximum speeds of over 80 m.p.h., I think hostages are being given to Fortune.

The production type of car naturally follows in development the successful use of new features of design established on specialist cars with smaller outputs, so that what may be a mild experiment or no experiment at all with a small output such as is typical in Europe may be well nigh revolutionary from the viewpoint of a thousand cars per day.

Thus I would consider that the development of rear-engined cars, independent springing, streamlined bodies and the like are engineering problems of a major nature which will need development in the face of a large existing industrial investment and of a purchasing public which is apt to be slow to respond. As to the technical desirability of the foregoing, there is indeed a logical case for all of them; but I feel that independent front-wheel suspension should be one of the first items to be tackled.

There are, however, two other main lines of development which may come relatively quickly because they do not call for fundamental changes in orthodox design. I refer to weight saving and supercharging. The use of light alloys, while apparently expensive, is in actual fact a method of producing a desired result, which, if it involves any increase in cost of production at all, is not a serious item when the result is considered.

The other line of development is that of supercharging, which is tantamount to weight reduction because it can increase performance to the extent of some 50 to 60 per cent in normal cars with a trifling increase in weight and cost.

I do not refer to supercharging as a means for developing

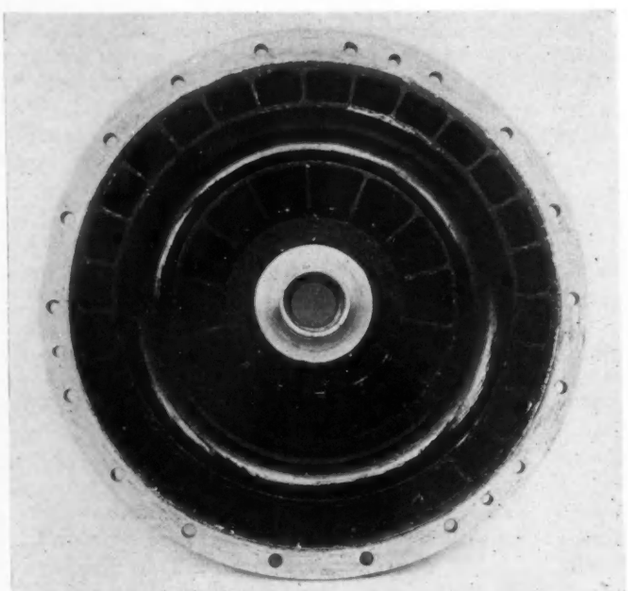


Fig. 12—The Driving Element of the Fluid Flywheel

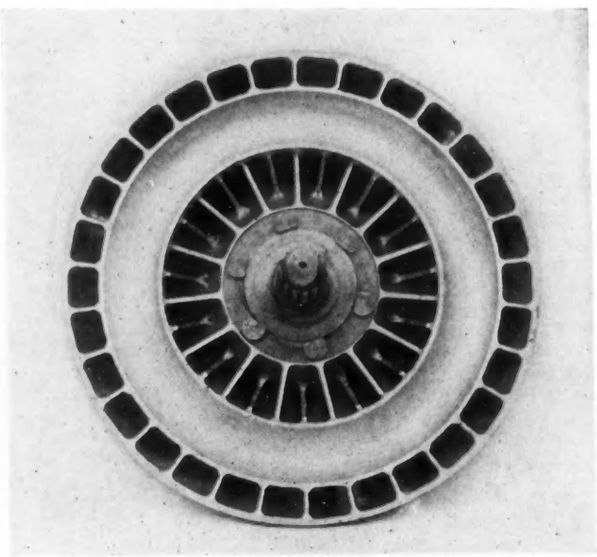


Fig. 13—The Driven Element of the Fluid Flywheel

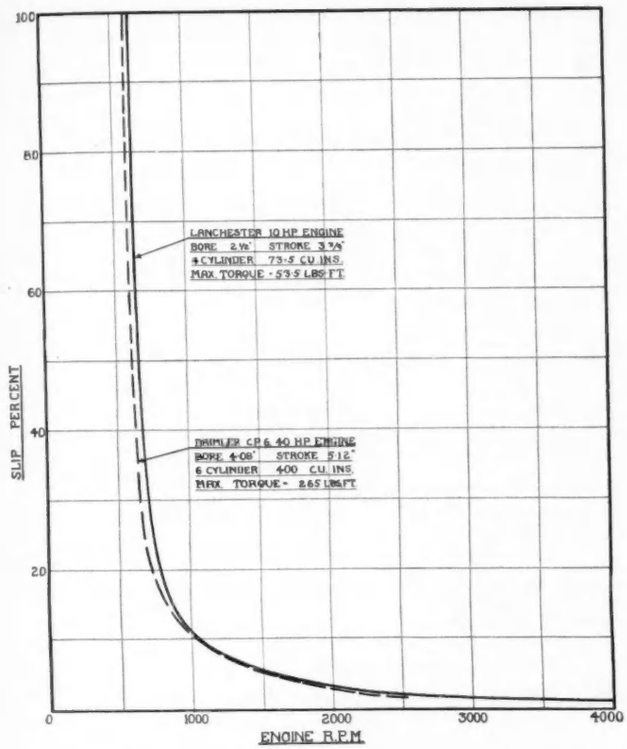

LANCHESTER 10 HP ENGINE
BORE 2 1/8" STROKE 3 3/4"
4 CYLINDER 73·5 CU INS.
MAX TORQUE - 53·5 LBS FT
DAIMLER CP 6 40 HP ENGINE
BORE 4·08" STROKE 5·12"
6 CYLINDER 400 CU INS.
MAX TORQUE - 265 LBS FT
SLIP PERCENT
ENGINE R.P.M.

Fig. 14—Slip Curves of Fluid Flywheel Used in Daimler Double-Deck Bus Having a 400-Cu. In. Engine and in a 10-Hp. Lanchester Car Having a 72-Cu. In. Engine

extremely high horsepower as in its application to aeronautical engines and to racing cars, but to the work that is now being done in making the supercharger as effective as possible in the lower engine-speed range and deliberately cutting down the supercharge at maximum engine speeds, thereby dodging the difficulties arising from heat flow if such is not done. Fig. 17 indicates the mean effective pressure obtained from an engine which normally had an indifferent performance by the application of supercharging.

The instant the problem is regarded in the above light it becomes possible to reduce the size of the inlet valves and inlet tract generally to about half its present area and to obtain an idling and slow-speed performance which is almost impossible otherwise.

Superchargers of the vane type can be made exceedingly silent. The whole system is full of potentialities in the not-so-remote future.

While I recognize as freely as anyone that in certain stages of the development of an industry the fulfilling of demand is the primary problem there comes a time when public taste begins to differentiate between good, better and best, and I see no evidence of any recognition of this in American practice. It is universally dominated by the dollar. In the whole range of American cars price and size are roughly equated and there seems to be no example of a small car built to the highest standards of design, workmanship and material.

I know the answer—namely, that if it were built it couldn't be sold—but I doubt its truth.

American architecture, both public and domestic, is evidence of standards of taste which are developed beyond mere effectiveness and of the fact that the American nation is becoming conscious of essential fineness and beauty.

Is it inconceivable that the time has come when the combining of high technique with artistic fitness may lead the way to a profitable satisfaction of the desires of a part of the community which already exists and which will increase?

Is there a man who is perfectly satisfied with his car and would not, if he could, pay more for his individual satisfaction?

I know many educated Americans who think along "custom built lines" so to speak and I seriously suggest that it would be well worth the while of the large American corporations either to set off a department in their own organizations to build special cars or to subsidize a few competitors in so doing. I say departmentalize or subsidize because I know of the many who have fallen by the wayside in trying to do what I suggest. Even the specialized car must have the backing of large research and engineering departments, to say nothing of capital.

The flexibility and adaptability of such departments or competitors would lead to far more developments than the average proving ground and give at least a hint of public taste a few years before it materializes in bulk.

At present, as I see it, the specification of next year is a hodge podge of ideas taken from competitors, absolutely sincere but misinformed opinions of ignorant golf-club critics, the almost equally unsound opinions of credulous salesmen who have always underrated the intelligence of the buying public, the confident prophecies of distributors who always think in terms of the past, plus what little the engineering department can wedge in on the side. But there is no reasonably accurate predictor of future public taste and the issues at stake are far too great to make progress other than slow. Hence my strong feeling that the establishment of a few prediction departments might be good for the future of production departments.

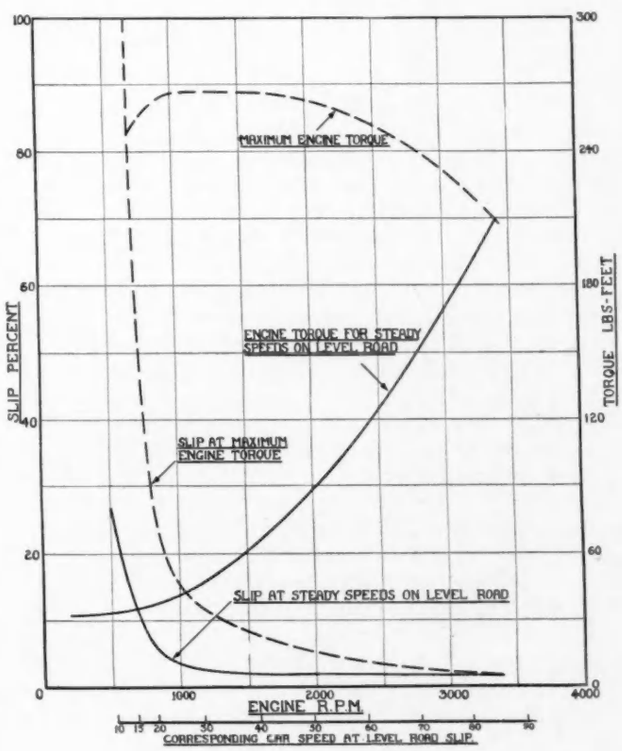

MAXIMUM ENGINE TORQUE
ENGINE TORQUE FOR STEADY SPEEDS ON LEVEL ROAD
SLIP AT MAXIMUM ENGINE TORQUE
SLIP AT STEADY SPEEDS ON LEVEL ROAD
SLIP PERCENT
TORQUE LBS-FEET
ENGINE R.P.M.
CORRESPONDING CAR SPEED AT LEVEL ROAD SLIP.

Fig. 15—A Typical Slip Curve

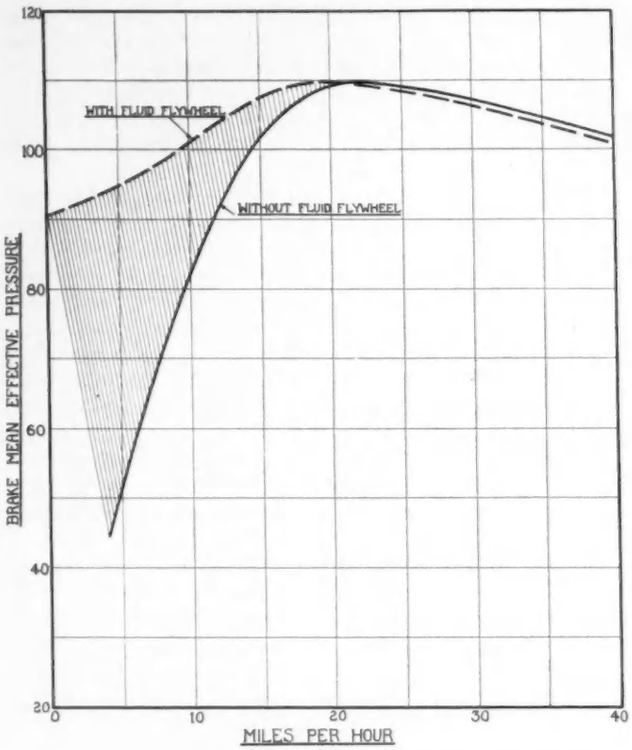


Fig. 16—Fluid Flywheel Effect on Transmitted Torque

In England such departments exist in a way with firms who produce sport-type cars which vary in detail from the corresponding production cars but enable all sorts of full-scale experiments to be made with the knowledge and willing connivance of the user.

At present, the man who wants a really first-class residence, "automobilely" speaking, has to buy a country mansion with twenty bedrooms when all he wants is the same character of home with four.

With all reserve I suggest that this is because your sales departments are easily deceived and underrate the intelligence of the buyer. You therefore are forced into designing automobiles in which performance is exalted at the expense of good honest comfort and of cost of running.

I believe that, not only in the U.S.A., the engineer is grudgingly regarded as competent to specify his designs. Why this is so is difficult to understand. Engineers are men with highly trained minds working from day to day at the task of trying to reconcile conflicting issues, are painstaking students of their competitors' work and, last but not least, constitute one of the few classes of the professional community upon whom honest thinking is literally forced. The engineer's mistakes are discovered, not by his peers, but in the simple process of ordinary usage of his product. It requires no brains to find that an engine may be noisy or overheat or that a spring suspension may be uncomfortable. It requires a great deal of brains to design so that these things will not occur.

Yet in spite of all this the lightest words of an inexperienced user to a salesman may have a weight in the process of determining the policy of design which is beyond computation.

However, here and there history is made by concerns who pay attention primarily to sound technique and secondarily to the oft-times wild demands of sales departments.

In this paper I have said very little about the large American car because in turnover and numbers it would scarcely seem to be the real basis of the American industry. But I should like to record for what it is worth my view that your large cars are really magnificent automobiles and I assure you they are appreciated by your fellow technicians abroad.

Whatever may happen in the U.S.A., the center of gravity of the motor trade in Europe has shifted and is shifting toward smaller cars, and the U.S.A. has followed Europe sufficiently often in the past to make it possible that this same process may repeat itself.

Does the American car fulfil the conditions of long life, economy of running and maintenance from the viewpoint of what can be attained without any undue sacrifice of essential performance by taking into account the use of the transmission system as the easiest, simplest and cheapest method of attaining these ends, or is it one in which sales are based upon a capacity for road performance in terms of acceleration and speed which are unsafe in the hands of the vast majority of drivers and but seldom used by the expert who knows that, of all the items making up the cost of upkeep of an automobile, it is speed which costs the money?

In a word, is the American car to hitch its wagon to the star of top-gear performance for ever in spite of engineering developments which make this wasteful and unnecessary?

The subject of this paper is a convenient peg upon which to hang a description of another method of doing the same thing. As to how far it is applicable to America's own problems and methods American engineers and only American engineers, can be the arbiters.

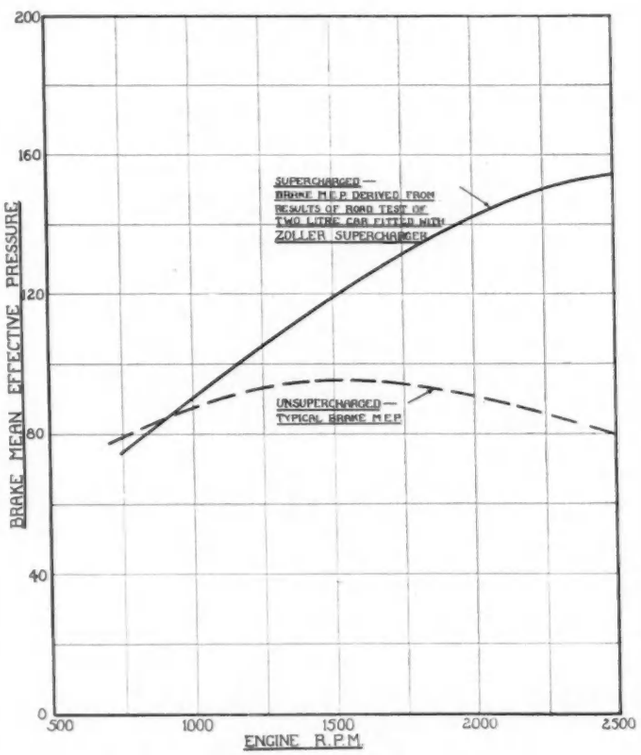


Fig. 17—Mean Effective Pressure Chart Showing Results Obtained by Application of Supercharging to an Engine Which Normally Had an Indifferent Performance